Downward Nominal Rigidities and Bond Premia*

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October 27, 2023

Abstract

We develop a simple New Keynesian macro-finance model with downward nominal rigidities and show that it helps explain both secular and cyclical movements in Treasury bond premia. The asymmetry in nominal rigidities implies that when inflation is high, prices are more flexible, leading to larger output and inflation responses to a productivity shock. As a result, when inflation is high, inflation becomes more volatile and covaries more strongly with traditional measures of risk such as aggregate consumption or the market return, consistent with the data. This mechanism can account for some of the downward trend in the bond premium since the early 1980s due to the decline of inflation. Our model also generates substantial cyclical variation in bond premia, as well as other compelling macroeconomic and finance properties, such as a flattening of the Phillips curve, negative skewness of output and positive skewness of inflation, and time variation in the covariance of stock and bond returns. Empirically, we show that the response to productivity shocks is larger when inflation is high.

JEL classification: E31, E32, E43, E44, G12.

Keywords: Term Premium, Phillips curve, Inflation, Asymmetry, Skewness.

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[*] We thank participants in presentations at Boston College, Brown University, U of Texas-Dallas, U of Washington, U of Wisconsin Madison, Purdue University, Banque de France, Zurich, the Midwest Macro and Society of Economic Dynamics meetings, the NBER Summer Institute, Barcelona BSE conference, the NFA Annual Meeting, the CICF Annual Meeting, and the Federal Reserve Banks of Chicago, Cleveland, Dallas, and San Francisco for comments, and especially our discussants Alex Hsu and Jinchen Tong. The views expressed here are those of the authors and do not necessarily represent those of the Federal Reserve Bank of Chicago or the Federal Reserve System.

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1 Introduction

Yields on long-term bonds have large secular and cyclical components. Understanding what drives yield changes is difficult, however. Notably, as is known at least since Fama and Bliss (1987) and Campbell and Shiller (1991), long-term yields are not simply expected future short rates, as assumed in the expectation hypothesis theory of the term structure. Rather, yields comprise a substantial, time-varying term premium, or bond premium, which represents the compensation required by investors to hold nominal long-term bonds over short-term bonds. But what are the economic mechanisms driving the variation in this bond premium?

In this paper, we develop a macro-finance asset pricing model with asymmetric nominal rigidities: prices are easier to raise than to cut. We show that this single, realistic ingredient can go some way towards understanding fluctuations in the bond premium. In particular, we show that our model, despite being highly stylized, can account for a significant fraction of the decline in the term premium since the 1980s, as documented in Wright (2011). Our model also generates substantial cyclical variation in term premia, consistent with Fama and Bliss (1987) and Campbell and Shiller (1991), as well as other compelling macroeconomic and finance properties, such as the asymmetry of output and inflation, and time variation in the covariance of stock and bond returns.

To understand the mechanism, note first that in our model, as in most New Keynesian models, an increase in productivity leads to higher output and lower inflation, as real marginal costs falls. This intuitive result - productivity acts as a “supply shock” - arises because the central bank does not perfectly accommodate the productivity shock, i.e. does not increase demand enough to match the newly available supply.[1] As a result, the inflation risk premium is positive, and nominal bonds are risky since inflation is high in “bad times” when productivity is low - they are exposed to “stagflation risk”.

In our model, the extent of nominal rigidities depends on the level of inflation - when inflation is low, prices become effectively “stickier”, because prices are more likely to be cut, which is more costly. As a result, the behavior of the economy changes markedly when inflation is low - i.e., the same productivity impulse has different effects depending on whether inflation is initially high or low. First, the response of inflation is naturally weaker when inflation is low - since prices are effectively “stickier”, inflation does not move. Second, the response of output is also weaker when inflation is low. Intuitively, a lower inflation in response to an increase in productivity helps generate higher demand,

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[1] There are a variety of reasons why this might be the case; most simply, the central bank does not observe productivity accurately in real-time. This feature holds under standard Taylor rule.

which helps increase output; when prices are stickier, this channel is weaker. Overall, the output-inflation covariance is smaller (in absolute value, i.e. less negative), which reduces the nominal bond premium.[2] Overall, in our model, the *level* of inflation is one determinant of term premia. In contrast, we show that if nominal rigidities are symmetric, this effect disappears.

We use this mechanism to understand the secular changes in macroeconomic and finance moments since the 1960s, in particular the changes in the volatility of output and inflation, in their covariance, in the yield curve, and in the covariance of bond and stock returns. To do so, we compare the data with our model's predictions when the inflation target changes. The underlying assumption is that inflation rose, then fell, in the 1970s, ultimately because the Fed let it rise, and eventually decided to make it fall.[3]

Our model also generates some cyclical predictability of bond returns based on the cyclical variation in inflation, and reproduces the fact that the term spread forecasts economic growth. We also use the model to illustrate how changes in monetary policy - for instance, a sharper focus on inflation stabilization - can have significant effects on asset prices.

Finally, in the last section, we provide some direct evidence for state-dependence in the response of both output and inflation to productivity shocks. Consistent with our theory, we find that when inflation is high, an increase in total factor productivity (TFP) increases GDP more, and reduces inflation more, than when inflation is low.

Our model is an extension of the canonical three-equation New Keynesian model (Gali (2008), Woodford (2003)). To that model we make only two modifications: first, we incorporate asymmetric price adjustment (as in Kim and Ruge-Murcia (2009)), and second, we incorporate recursive preferences (as in Epstein and Zin (1989), Weil (1990)) with high risk aversion to match the level of bond premia. Two parameters - the level of risk aversion and the degree of asymmetry in price adjustment costs - govern the differences with the standard model and allow us to cleanly demonstrate its properties. In particular, we parameterize the model so that it matches both the positive skewness inflation, and the low probability that inflation is below 1%. Our model is deliberately kept stylized to allow a transparent numerical analysis. But of course, our model does not encompass many other mechanisms driving the yield curve.

Our contribution is to offer a simple economic mechanism to govern time-variation

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[2] Real term premia also fall, as they are determined (among others) by the autocovariance of consumption growth, which becomes smaller, but this effect is small for our calibration.

[3] For a recent clear exposition of this view, see Bernanke (2022). As an alternative mechanism, we can subject the model to a sequence of negative productivity shocks that generate the high inflation level of the 1970s, to which the Fed does not react adequately. This leads to very similar conclusions.

in covariances of macroeconomic quantities and asset returns, and term premia. We provide some evidence for time variation in these covariances in a manner consistent with the model. While much work in finance has documented variation in term premia, there are few models that provide an endogenous mechanism for this variation.[4] We find downward nominal rigidities compelling because there is strong empirical support for it.See among many others, **?**, Kahn (1997), Peltzman (2000), Nakamura and Steinsson (2008), Klenow and Malin (2010), Basu and House (2016), Kurmann and McEntarfer (2019), Elsby and Solon (2019), Grigsby et al. (2021), and Hazell and Taska (2020). Asymmetry of nominal rigidities also has a long history in macroeconomics, dating back to Keynes (1936) and Tobin (1972). Many studies emphasize asymmetric wage, rather than price, rigidities, for which the empirical support is stronger. For simplicity, in the paper we focus on a model with flexible wages; ghowever, in the appendix, we set up and solve a model with both wage and price asymmetric rigidities, and show that it can generate similar predictions. While the relevance of the downward nominal rigidities is largely acknowledged by macroeconomists and policymakers, its implications for asset prices have been overlooked. One of our contributions is to close this gap.

The paper is organized as follows. The rest of the introduction reviews briefly the related literature. Section 2 presents some motivating evidence on the relation between term premia and inflation. Section 3 introduces a DSGE model with asymmetric nominal rigidities and Section 4 calibrates it and presents the key quantitative results. Section 5 provides additional result and robustness. Section 6 provides some empirical evidence in favor of our key mechanism. Section 7 concludes.

Related Literature

We first build on a small macroeconomic literature that studies the effect of downward rigidities, including Kim and Ruge-Murcia (2009) that we follow closely, as well as Benigno and Antonio Ricci (2011), Abbritti and Fahr (2013), Daly and Hobijn (2014), Schmitt-Grohé and Uribe (2016), and Jo and Zubairy (2022) among others. We also relate to the literature emphasizing asymmetries over the business cycle (Neftci (1984), Dupraz et al. (2019), Dew-Becker et al. (2021), Dew-Becker (2022)). Like Ascari and Sbordone (2014), Ascari and Rossi (2012), Ascari (2004), we are interested in the implications of trend inflation, which is often ignored in New Keynesian models that focus on dynamics around a zero inflation steady-state.

Second, we relate to the huge finance literature that studies the term structure of interest rates. Much of this work use affine models (among many others, see Kim and Wright

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[4] Habit preferences offer an alternative way to endogenize time variation in risk premia, as in Pflueger (2022). See the literature review for a more detailed discussion.

(2005), Christensen et al. (2011), Adrian et al. (2013a), D'Amico et al. (2018), Ang et al. (2008), Hordahl and Tristani (2014), Roussellet (2018).) We will use some of these estimates in Section 2. Representative agent endowment economy models have also been proposed, e.g. Piazzesi and Schneider (2006), David and Veronesi (2013), Bansal and Shaliastovich (2013), and Song (2017). Several of these papers also emphasize "stagflation risk", and note that there appear to be changes in macroeconomic regimes over time. Our contribution relative to these papers is to endogenously generate the time-varying correlations between inflation and growth that are taken as primitives in these studies. More closely related to our work are studies that endogenize consumption and inflation using production models with nominal rigidities (a.k.a., "New Keynesian DSGE models"). Some key contributions include Rudebusch and Swanson (2008), Rudebusch and Swanson (2012), Li and Palomino (2014), Christiano et al. (2010), Palomino (2012), Swanson (2015a), Pflueger and Rinaldi (2022), Weber (2015).

In particular, most closely related are some studies that also use a macroeconomic model to understand the variation in various macro-finance moments, notably Campbell et al. (2020), Branger et al. (2016), Pflueger (2022). These papers emphasize structural breaks in monetary policy rules and in the structure of shocks hitting the economy rather than endogenous time variation in propagation as in our model. Some work focuses on the role of the zero lower bound (ZLB), including our previous paper Gourio and Ngo (2020), Nakata and Tanaka (2016), Datta et al. (2018), and Bilal (2017), which is another mechanism for the changing covariance, with somewhat different implications, and which explains different periods and phenomena. Finally, to the extent that asymmetric rigidities capture labor market frictions, our paper is also related to the growing literature in macro-finance on this topic (e.g. Favilukis et al. (2020), Donangelo (2014), Donangelo et al. (2019), Favilukis and Lin (2016), Belo et al. (2014)).

2 Motivating Evidence

This section presents some evidence on the association between the level of inflation and various proxies for the riskiness of bonds and inflation. In a first part, we use as proxy the term premium estimated by an affine term structure model. In a second part, we estimate volatilities and covariances using rolling windows.

Regressors	Dependent variable: 10-year ACM Term Premium (1)	(2)	(3)	(4)
Core PCE inflation	0.259***		0.248***	
	(0.080)		(0.089)	
PCE inflation		0.174**		0.151**
		(0.067)		(0.080)
Time			0.000	-0.000
			(0.000)	(0.001)
Number of observations	733	733	733	733

Table 1: Association between Adrian et al. (2013b) 10-year term premium and inflation. Standard errors in parentheses are HAC with 36 lags. ***, **, * indicate statistical significance at 1%, 5%, and 10%, respectively. The data range from 1960m1-2022m10. The code to produce this table is termpremium_p in the folder Empirical/do.

2.1 Term premia implied by affine models

A large literature has developed sophisticated affine term structure models to infer term premia from bond prices and other observables. Figure 1 presents a variety of estimates, from Kim and Wright (2005), Christensen et al. (2011), Adrian et al. (2013a) (thereafter ACM), and D'Amico et al. (2018). Each estimate relies on a different statistical model and may use different data. Overall, these estimates move broadly similarly, both along the cyclical margin and along the secular margin. In particular, the low frequency movements appear to follow those of inflation or nominal interest rates during this period. To confirm this, we use the Adrian et al. (2013b) 10-year term premium estimate (thereafter ACM) since it has the longest available history - covering both the rise and fall of inflation in the 1970s. In figure 2 we depict the ACM estimate together with core inflation, and in table 1 we measure the association using the regression:

$$TP_t = \beta_0 + \beta_1 \pi_t + \beta_2 t + \varepsilon_t,$$

where TP_t is the ACM estimate of the 10-year nominal term premium, π_t is either PCE or core PCE inflation (year-over-year), and we may include a linear trend as control. According to the table, a 1% decrease in inflation is associated with a decrease in the term premium of 15-26bps. This result is in line with the findings of Wright (2011) who documents a reduction in term premia across many countries during the 1980s and 1990s.

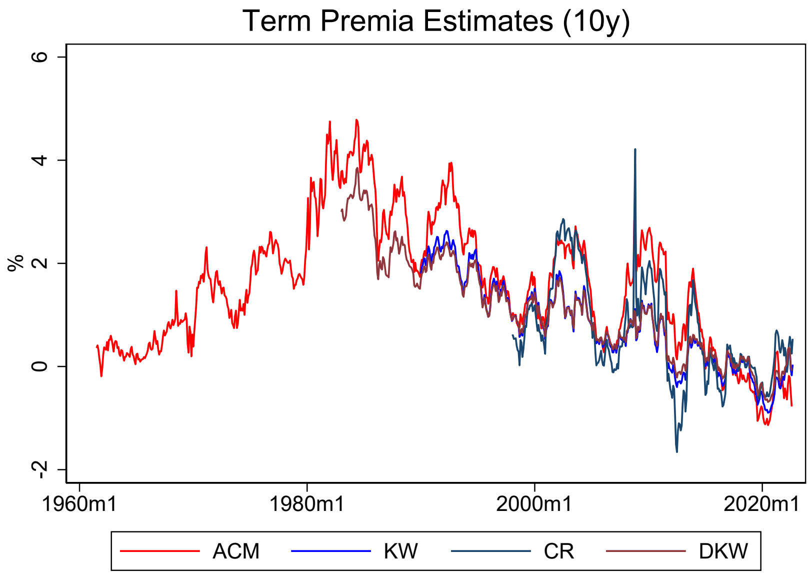

Figure 1: Estimates of 10-year nominal term premium from affine term structure models. ACM denotes Adrian et al. (2013b), KW is Kim and Wright (2005), DKW is D'Amico et al. (2018), and CR is Christensen et al. (2011).

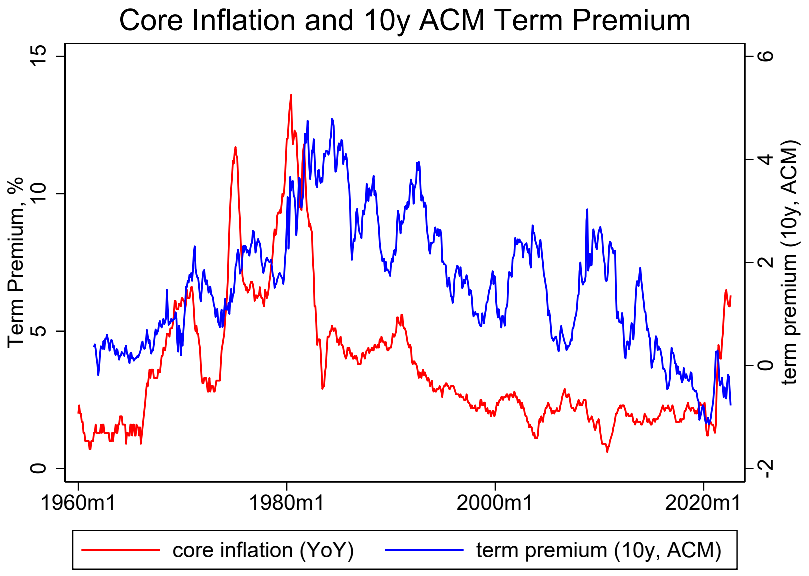

Figure 2: The figure depicts the 10-year nominal term premium by Adrian et al. (2013b) and realized year-over-year core CPI inflation.

2.2 Time-varying Covariances

Another approach to measuring the riskiness of bonds is to estimate the covariance of inflation with macroeconomic proxies for marginal utility, such as consumption or the market stock return (corresponding to the consumption or market CAPM measure of riskiness). Even more simply, we can look at the volatility of inflation or yields. We estimate these moments at each point in time by using a simple rolling window.[5]

Figure 3 shows how these moments vary with the level of inflation. Consider the top left panel. For each date between 1965 and 2015, we calculate the current inflation and the volatility of inflation (using the corresponding 13-year centered rolling window, so our data range from 1959q1 through 2019q4), and plot one against each other, together with a simple regression line. This panel shows that higher level of inflation is associated with more volatile inflation - a well-known empirical regularity in the applied macroeconomics literature.

Similarly, the other panels show that higher inflation is associated with (i) higher volatility of GDP; (ii) higher volatility of interest rates; (iii) a more negative covariance of GDP growth and inflation; (iv) a more negative covariance of real stock returns and inflation; (v) a more positive covariance of real stock returns and the real 10-year bond return. All of these changes suggest that inflation is more risky when it is high - and hence, bonds are more risky - consistent with the term premia estimates, which use a very different identification.

These results are not new - they confirm the findings of a large literature that documents changes over time in these associations.[6] One difference with some of the existing literature is that we incorporate data from the low-inflation 1960s, before the Great Inflation, and show that, for, the most part, they line up relatively well with the low-inflation post 1985 period. This suggests that the changes observed in these associations are not simply due to one of the many changes during the 1980s - but rather, the actual level of inflation might be, in itself, an important factor.

While the idea that a high level of inflation is associated with (and perhaps causes) volatile inflation, is intuitive, it is not a prediction of standard monetary models, which typically explain the average level of inflation, on the one hand, by the average growth of money growth or the average interest rate (the inflation target), and the volatility of inflation, on the other hand, by the volatility of underlying shocks and their propagation - factors which in principle have no relation to each other. For this reason, he relation

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[5] We obtain similar results if we estimate conditional moments by calculating the volatility or covariance of the residuals from a VAR.

[6] See for instance Piazzesi and Schneider (2006), Campbell et al. (2009), and the references therein.

between level and volatility of inflation is a longstanding puzzle.[7] We now explore one potential explanation: asymmetric nominal rigidities.

3 Model

Our model builds on the standard New Keynesian model as outlined in Gali (2008) and Woodford (2003). We depart from this standard model in two ways. First, as many authors in the asset pricing literature, we use recursive preferences (Epstein and Zin (1989), Weil (1990)) with high risk aversion to match the observed level of risk premia. Second, we introduce asymmetric nominal rigidities following the work of Kim and Ruge-Murcia (2009).

3.1 Household

The representative household works, consumes, and decides how much to save in various assets. Following the simplest New Keynesian model, there is no capital. Because the equilibrium is not affected by the number and type of assets available, we present the household problem using only a short-term nominal risk-free bond.[8] We discuss later in subsection 3.5 how assets are priced.

We use the formulation of recursive preferences introduced by Rudebusch and Swanson (2012). The flow utility of consumption is:

$$u\left(C_t, N_t\right) = \frac{C_t^{1-\sigma}}{1-\sigma} - \chi \frac{N_t^{1+\nu}}{1+\nu},$$

and the intertemporal utility is:[9]

$$V_t = (1-\beta)\, u(C_t, N_t) + \beta E_t \left(V_{t+1}^{1-\alpha} \right)^{\frac{1}{1-\alpha}}.$$

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[7] See for instance Friedman (1977).

[8] Agents are Ricardian, i.e. they recognize that government debt is not net wealth, and hence the quantity and types of bonds issued by the government is irrelevant for the equilibrium - the bonds are all effectively in zero net supply.

[9] Note that, if the parameters lead to a negative flow utility $u(C_t, N_t)$, we define utility as:

$$V_t = (1-\beta)\, u(C_t, N_t) - \beta E_t \left((-V_{t+1})^{1-\alpha} \right)^{\frac{1}{1-\alpha}}.$$

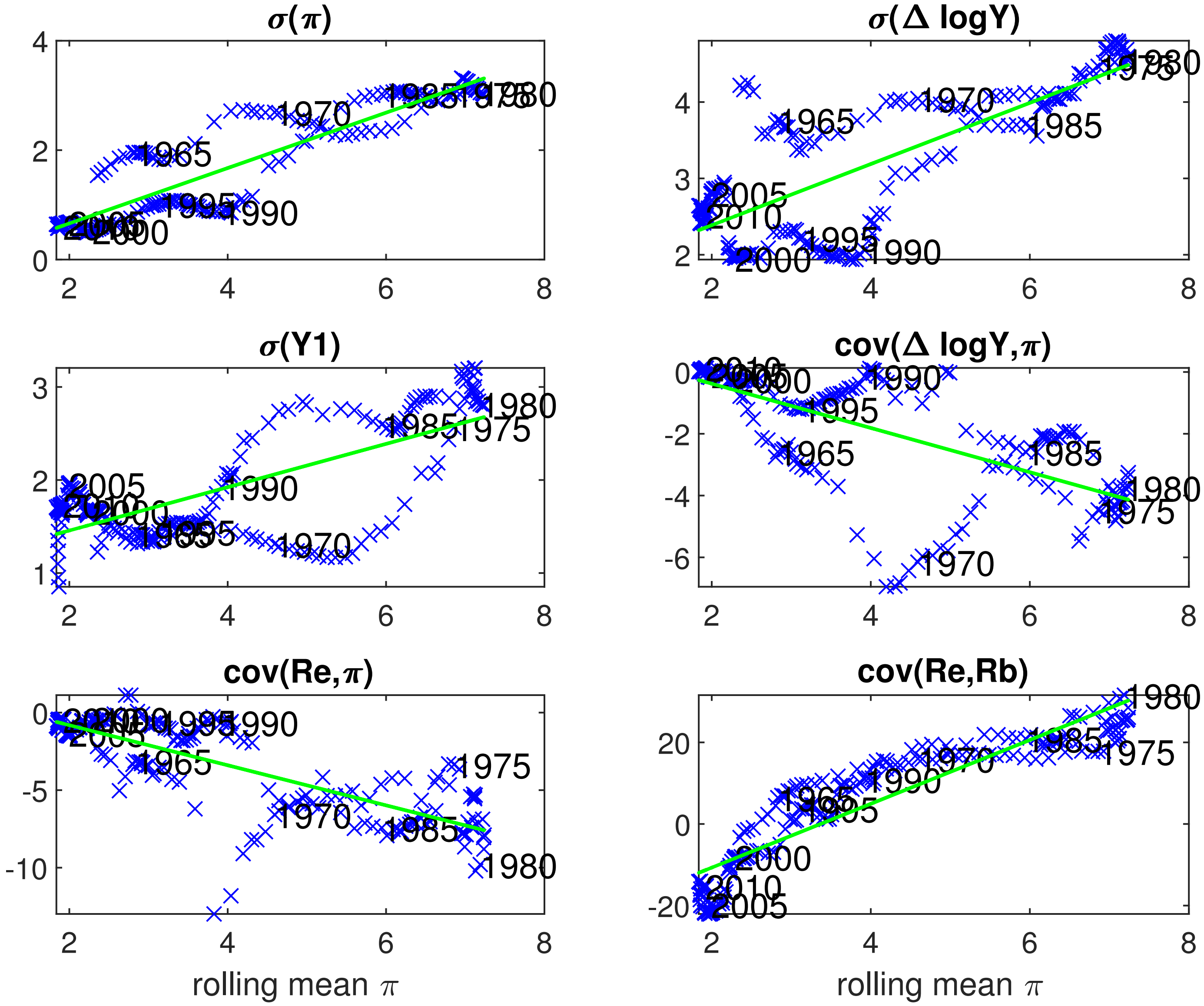

Figure 3: Each panel plots a moment against the local mean of inflation, where both are estimated on a 13-year centered rolling window. The moments are the volatility of inflation (top left), of GDP growth (top right), of the 3-month T-bill rate (middle left), the covariance of GDP growth and inflation (middle right), the covariance of real equity return and inflation, and the covariance of real equity return with the real 10-year bond return. US quarterly data, 1959-2019; inflation is measured as core CPI.

The household budget constraint is:

$$P_tC_t + B_t = W_tN_t + H_t + R_{t-1}B_{t-1},$$

where B_t is the quantity of one-period risk-free assets bought, H_t are firms' profits, rebated to the household, P_t is the price level, and W_t is the wage rate.

Labor supply is governed by the usual condition:

$$\frac{W_t}{P_t} = -\frac{u_2\left(C_t, N_t\right)}{u_1\left(C_t, N_t\right)} = \chi C_t^{\sigma} N_t^{v}, \tag{1}$$

and optimal consumption is determined by the usual Euler equation linking the nominal short-term interest rate to the "marginal rate of substitution" a.k.a. nominal stochastic discount factor:

$$E_t\left[R_t M_{t+1}^{\$}\right] = 1, \tag{2}$$

where $R_t \equiv Y_t^{\$(1)}$ is the gross nominal yield on a one-period risk-free bond, and the nominal stochastic discount factor is

$$M_{t+1}^{\$} = \frac{M_{t+1}}{\Pi_{t+1}}, \tag{3}$$

where Π_{t+1} is gross inflation P_{t+1}/P_t, and the real stochastic discount factor is

$$M_{t+1} = \beta\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}\left(\frac{V_{t+1}}{E_t\left(V_{t+1}^{1-\alpha}\right)^{\frac{1}{1-\alpha}}}\right)^{-\alpha}. \tag{4}$$

3.2 Production and price-setting

There is a measure one of identical monopolistically competitive firms, each of which operates a constant return to scale, labor-only production function:

$$Y_{it} = Z_tN_{it}, \tag{5}$$

where Z_t is an exogenous stochastic productivity process, common to all firms. Each firm faces a downward-sloping demand curve coming from the Dixit-Stiglitz aggregator with elasticity of demand ε:

$$Y_{it} = Y_t\left(\frac{P_{it}}{P_t}\right)^{-\varepsilon}, \tag{6}$$

where P_t is the price aggregator:

$$P_t = \left(\int_0^1 P_{it}^{1-\varepsilon} di \right)^{\frac{1}{1-\varepsilon}}.$$

Following Rotemberg (1982) and Ireland (1997) we assume that each intermediate goods firm i faces costs of adjusting prices. These costs are measured in final goods. The adjustment cost is proportional to aggregate output, and a convex function of the price change:

$$AC_t = G\left(\frac{P_{it}}{P_{it-1}}\right) Y_t,$$

where G is an increasing and convex function.

The problem of firm i is to maximize the present discounted value of real profits, net of adjustment costs:

$$\max_{\{P_{it+j}\}} E_t \sum_{j=0}^{\infty} M_{t,t+j} \left[\left(\frac{P_{it+j}}{P_{t+j}} - mc_{t+j} \right) Y_{it+j} - G\left(\frac{P_{it+j}}{P_{it+j-1}} \right) Y_{t+j} \right]$$

subject to its demand curve (6). Here mc_t denotes the real marginal cost, equal to W_t/Z_t. The first term in this expression reflects the real profit per unit sold, and the second term the cost of changing prices. Note that in equilibrium, all firms choose the same price and produce the same quantity (i.e., $P_{it} = P_t$ and $Y_{it} = Y_t$). Taking first-order conditions and imposing this equilibrium condition yields the optimal pricing rule:

$$\left(1 - \varepsilon + \varepsilon \frac{w_t}{Z_t} - \Pi_t G'\left(\Pi_t\right)\right) Y_t + E_t \left[M_{t,t+1} G'\left(\Pi_{t+1}\right) \Pi_{t+1} Y_{t+1} \right] = 0. \tag{7}$$

If there are no costs to adjusting prices, this formula reduces to the Lerner rule. With adjustment costs, this equation yields a relation between inflation and current (and future) marginal costs, i.e. a Phillips curve.

Much of the literature assumes a symmetric, quadratic adjustment cost:

$$G\left(x\right) = \frac{\phi}{2}\left(x - \overline{\Pi}\right)^2, \tag{8}$$

where ϕ is the adjustment cost parameter which determines the degree of nominal price rigidity, and $\overline{\Pi}$ the degree of inflation which implies zero costs, which can be thought of as the "indexation" trend for the economy. As is well known, in this quadratic case, and if $\overline{\Pi} = 1$, then this (Rotemberg) Phillips curve is equivalent to that implied by the

Calvo model (to a first-order around zero inflation).[10] In contrast, we follow Kim and Ruge-Murcia (2009) who use a linex function to model adjustment costs:

$$G(x) = \frac{\phi}{\psi^2}\left(e^{-\psi(x-\overline{\Pi})} + \psi\left(x - \overline{\Pi}\right) - 1\right). \tag{9}$$

This function captures that reducing prices at a rate below $\overline{\Pi}$ is more costly than increasing prices at a rate above $\overline{\Pi}$. The linex functional form has been used in various contexts to model asymmetry. It is convenient for two reasons. First, it neatly separates the role of the size of adjustment costs (governed by the parameter ϕ) from that of the asymmetry (governed by ψ). Second, it nests the standard quadratic specification: when $\psi \to 0$, the specification converges to the usual quadratic one.[11] This will allow us to demonstrate clearly the role of the asymmetry by varying ψ.

Some further intuition can be gained by log-linearizing the Phillips curve around a value Π^*, and obtain:

$$\pi_t = \kappa\widehat{MC}_t + \frac{\beta J(\Pi^*)}{J'(\Pi^*)}E_t\left(\widehat{M}_{t+1} + \widehat{Y}_{t+1} - \widehat{Y}_t\right) + \beta E_t(\pi_{t+1}), \tag{11}$$

where π_t is the net inflation rate, and hats denote log-deviations. This equation is closely related to the standard NKPC, but the slope is now

$$\kappa = \frac{\varepsilon - 1}{J'(\Pi^*)} + \frac{J(\Pi^*)(1-\beta)}{J'(\Pi^*)}. \tag{12}$$

In contrast, in the commonly used quadratic case with a zero inflation target, and linearizing around zero inflation, we have$J(\Pi^*) = 0$ so the middle term disappears and the slope is the usual

$$\kappa = \frac{\varepsilon - 1}{\phi}. \tag{13}$$

In our model, the slope of the Phillips curve depends on the level of inflation Π^*: the higher the level of inflation, the larger the slope.[12]

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[10] See Miao and Ngo (2016) for a detailed comparison of Rotemberg and Calvo models of price stickiness.

[11] The second point can be seen easily using L'Hospital rule, and the intuition for the first point can be gleaned from a Taylor expansion:

$$G(x) \approx \frac{\phi}{2}\left(\left(x - \overline{\Pi}\right)^2 - \frac{\psi}{3}\left(x - \overline{\Pi}\right)^3\right), \tag{10}$$

which shows that a larger ψ makes the costs lower for positive adjustments (above $\overline{\Pi}$) and higher for negative adjustments (below $\overline{\Pi}$), while a larger ϕ increases adjustment costs for all adjustments.

[12] Ascari (2004) and Ascari and Sbordone (2014) analyze the role of trend inflation in the quadratic cost

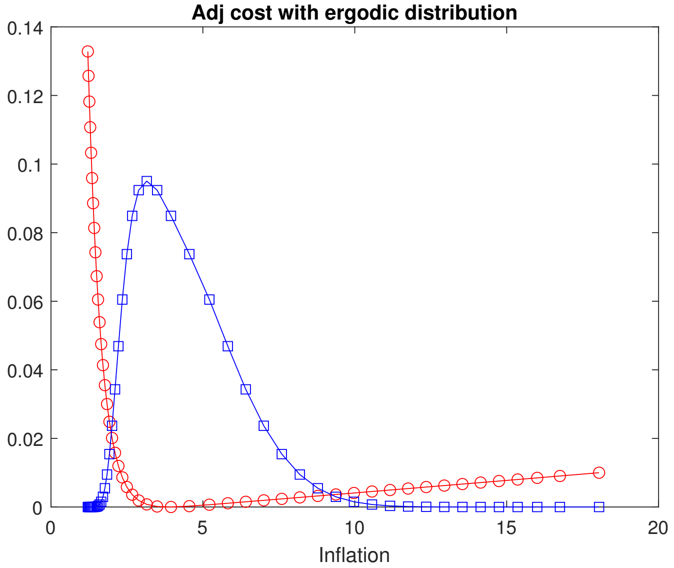

Figure 4: Adjustment cost distribution and invariant distribution of inflation in the model.

Finally, following Miao and Ngo (2016), we assume that price adjustment costs are rebated to households.[13] Hence, the aggregate resource constraint is simply

$$C_t = Y_t. \tag{14}$$

3.3 Productivity Process

We assume that productivity follows an AR(1) process with normal innovations:

$$\log Z_t = \rho_z \log Z_{t-1} + \varepsilon_{z,t},$$

with $\varepsilon_{z,t}$ i.i.d $N(0, \sigma_z^2)$. By imposing normal shocks, we force all skewness or higher moments to be generated endogenously through the model.

3.4 Monetary policy

We assume that monetary policy follows the following rule, in the spirit of Taylor (1993):

$$\log R_t = \log R^* + \phi_\pi(\log \Pi_t - \log \Pi^*) + \phi_y(\log Y_t - \log Y^*), \tag{15}$$

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model.

[13] We do so in the order to make the analysis more transparent, but this has little effect on our results.

where R_t is the gross nominal interest rate on a one-period risk-free bond; ϕ_π and ϕ_y are the responsiveness to inflation and GDP respectively; and R^* and Π^* and Y^* are constants.[14] We abstract from the zero lower bound, which we studied in detail in Gourio and Ngo (2020), and from unconventional policies.

The original rule in Taylor (1993) assumes that the central bank responds to the deviation of GDP from potential GDP. Often, researchers assume that potential GDP is the level of GDP that would prevail in an economy without price stickiness (the "natural level of output"), i.e. in our model $Y^{ss} Z_t^{\frac{1+v}{\sigma+v}}$, where Y^{ss} is the nonstochastic steady-state level of output. In practice, potential GDP is difficult to estimate, especially in real time. Partly motivated by this, we follow Fernandez-Villaverde et al. (2015) and Swanson (2015a) and assume that the central bank responds to the deviation of GDP from a statistical "trend"; given that our model abstracts from long-run growth, it is natural to define the trend simply as the nonstochastic level of output, $Y^* = Y$. We discuss in section 5 the importance of this assumption, and more generally how different policy rules affect our results.

3.5 Asset prices

This section describes the various asset prices that we calculate in the model. While our model description only considered a short-term bond, we can allow the household to hold any other asset in zero net supply and calculate its value, since this does not affect the equilibrium of the model. We use the standard recursions to calculate real and nominal zero-coupon bond prices, yields, and returns. Briefly, the price of a n-maturity nominal bond satisfies

$$P_t^{\$(n)} = E_t \left[M_{t+1}^{\$} P_{t+1}^{\$(n-1)} \right], \tag{16}$$

with $P_t^{\$(0)} = 1$. From these bond prices, we deduce log gross yields as

$$y_t^{\$(n)} = \log Y_t^{\$(n)} = -\frac{1}{n} \log P_t^{\$(n)}, \tag{17}$$

and log gross (real) holding period return as

$$r_{t+1}^{\$(n)} = n y_t^{\$(n)} - (n-1) y_{t+1}^{\$(n-1)} - \log \Pi_{t+1}. \tag{18}$$

Similarly, we obtain the prices, yields and returns of real bonds, and we define inflation compensation (a.k.a. breakevens) as the difference between the log nominal yield and the

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[14] Clearly, only the overall intercept $\log R^* - \phi_\pi \log \Pi^* - \phi_y \log Y^*$ matters.

log real yield at a given maturity:

$$IC_t^n = \log Y_t^{\$,(n)} - \log Y_t^{(n)}. \tag{19}$$

We define the risk-neutral nominal log yield as the average expected future short-term log nominal)yields over the remaining lifetime of a bond:

$$y_t^{rn\$(n)} = \frac{1}{n} E_t \sum_{k=0}^{n-1} y_{t+k}^{\$(1)},$$

and similarly for nominal bonds. With this in hand, the (log) term premium of a bond at maturity n is the difference between actual and risk-neutral yields:

$$tp_t^{\$(n)} = y_t^{\$(n)} - y_t^{rn\$(n)}.$$

The term premium measures the expected return per year on a bond of maturity n if it is held to maturity, over holding short-term bonds. On average, the term premium equals the slope of the yield curve. Term premia and holding period returns are two related ways to measure the riskiness of bonds - the term premium smoothes out the average excess returns over the remaining maturities. We can also break out the nominal term premium into the real term premium and the inflation term premium.

Finally, we also price a stock, which we define, following Abel (1999), as an asset with payoff $D_t = C_t^{\lambda}$, where $\lambda \geq 1$ reflects leverage.[15] The real stock price P_t^s satisfies the usual recursion

$$P_t^s = E_t \left[M_{t+1} \left(P_{t+1}^s + D_{t+1} \right) \right],$$

and the gross stock return is $R_{t+1}^s = (P_{t+1}^s + D_{t+1}) / P_t^s$.

4 Quantitative results

This section studies the quantitative implications of the model presented in the previous section. We first discuss our calibration procedure. We then explain the key economic mechanisms by showing how the response of the economy to productivity shocks changes with the level of inflation when nominal rigidities are asymmetric. We then dis-

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[15] We do not define a stock as a claim to profits, because profits tend to be countercylical in this model. A number of extensions have been proposed to explain this cyclicality, for instance fixed costs, sticky wages, or financial leverage (see, for instance, Li and Palomino (2014)). We do not incorporate these extensions in the interest of simplicity.

Parameter	Description and source	Value
	A. Taken from the literature	
σ	IES is 0.5	2
υ	Frisch labor supply elasticity is 0.66	1.5
χ	Calibrated to achieve the steady state labor of 1/3	40.66
ε	Gross markup is 1.15	7.66
ϕ_π	Weight on inflation in the Taylor rule	2
ϕ_y	Weight on output in the Taylor rule	0.5/4
ρ_z	Persistence of technology shock	0.99
ϕ	Adjustment cost	78
	B. Calibrated to match key moments	
R^*	Intercept of Taylor Rule	1.0101
σ_z	Std. dev. of the technology innovations (%)	1.12
ψ	Asymmetry parameter	884
$\overline{\Pi}$	Inflation to be indexed, 3.64% per year	1.0091
β	Subjective discount factor	0.991
α	Curvature with respect to next period value (note: CRRA=59)	-82

Table 2: Model parameters.

cuss the ability of the model to match some basic moments. Finally, we present our main result, namely that the level of inflation affects inflation riskiness in a quantitatively similar way as in the data.

4.1 Parametrization and solution method

Table 2 presents the baseline parameters that we use for our quantitative analysis. A first set of parameters, shown in Panel A, are set a priori based on external considerations, and are consistent with the literature. In particular, we set the intertemporal elasticity of substitution (IES) of consumption $1/\sigma$ to 0.5, and the Frisch elasticity of labor supply to 2/3. We also set the gross markup to 1.15, corresponding to a demand elasticity $\varepsilon = 7.66$. The price adjustment cost parameter is $\phi = 78$, corresponding to the Calvo probability of 0.75 of keeping prices unchanged (in the symmetric case), i.e. a half-life of half a year for prices. We set the weight on inflation in the Taylor rule to $\phi_\pi = 2$ and the weight on output gap ϕ_y = 0.1254 (which translates into the usual 0.5 response once the interest rate is annualized). All of these values are standard in the literature, see for example Woodford (2003), Gust et al. (2017), and Arouba et al. (2018). We further set the persistence of the TFP shock to 0.99, in order to roughly replicate the high persistence of inflation, but as we explain below, most of our results are not very sensitive to this assumption.

Panel B shows the parameters that we calibrate internally using simulated method of moments. The main challenge is to estimate the parameters governing the asymmetry of the price adjustment cost. Our strategy relies on two robust features of US inflation data: first, inflation is significantly positively skewed, so that the "upside risk" to inflation is much larger than the "downside risk"; second, negative inflation is very rare. Together, these two features allow us to identify the size and location of the asymmetry. Specifically, in our calibration sample (1979q4-2008q4), the probability of inflation (Core PCE) below 1% is 1.7% (corresponding to 2 observations out of 117 quarters), and the skewness is 1.55.[16] To these two key moments, we add the mean and standard deviation of inflation, and the mean short-term (90 days T-Bill) and long-term (10-year T-note) yields. These four moments naturally identify the inflation target, the volatility of shocks, the discount factor, and the level of risk aversion.

Table 3 show that we can match these moments almost perfectly. The resulting parameters, are shown in table 2. Of note, the asymmetry parameter is large, at 884, and the baseline inflation is also fairly high, at 3.64% per year. This is because the model must generate regular inflation in the 2-3% range, but rarely below. Finally, the risk aversion α parameter is $\alpha = -82$, which corresponds to a relative risk aversion to consumption (CRRA) of 59 once we take into account the curvature parameters on consumption and labor in the flow utility (see Rudebusch and Swanson (2012), Swanson (2015b)). This is what is required to match the slope of the yield curve, i.e. the difference between the 10-year Treasury yield and the short term rate, which is 1.73% in our data. Our model is a stylized New Keynesian model, so it requires a high risk aversion to generate a sizable slope for the yield curve. Clearly, this parameter does not reflect the preferences of any single individual. Rather, it captures the aversion of the macroeconomy to fairly small fluctuations in aggregate consumption, as inferred from asset prices.[17]

Due to the presence of asymmetric adjustment costs, and given our focus on asset prices, we need to solve the model using nonlinear methods. We solved the model using two differnet methods: first, a simple policy function iteration after discretizing the productivity shocks with a Markov chain; second, projection methods with cubic splines, similar to Fernandez-Villaverde et al. (2015), Miao and Ngo (2016), and Ngo (2018).

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[16] We choose this post-Volcker, pre-ZLB sample to reduce the risk of structural breaks in monetary policy rule.

[17] The value we use is actually smaller than what is found in related studies; for instance Swanson (2015b) requires α to be -338, or CRRA to be 600, to generate the equity premium of only 1.5% per annum. Rudebusch and Swanson (2012) require α to be -396, or CRRA to be 200, to generate a term premium of 1.06%.

	Data	Model
$E(\pi)$	3.14	3.14
$\sigma(\pi)$	1.97	1.97
$Skewness(\pi)$	1.55	1.55
$Prob(\pi < 1\%)$	1.71	1.78
$E(Y^{\$(1)})$	5.63	5.63
$E(Y^{\$(40)})$	7.36	7.36

Table 3: SMM target moments and model moments. The data moments are calculated over 1979q4-2008q4.

4.2 State-Dependent Impulse Response Functions

To understand the mechanics of the model, it is useful to study how the economy responds to a productivity shock, and how this response depends on the level of inflation. Figure 5 display (generalized) impulse response function (GIRFs) to a one-standard deviation innovation to TFP, for two parametrization of the model. In the first one, we set R^* so that average inflation 2% (red line); in the other one, 4%.[18]

First, note that a higher productivity leads to higher GDP and lower inflation - that is, they are "stagflationary". Lower inflation can be understood as reflecting lower lower marginal costs of productions. Alternatively, lower inflation arises because demand does not expand enough to align with the newly available supply - that is, the central bank does not lower the interest rate enough. These features are standard in New Keynesian models.

The novel result of the paper is the *difference* in the responses at high vs. low average inflation. When the inflation target is higher, average inflation is higher, and GDP responds more positively to a TFP shock, and inflation more negatively. Intuitively, at low levels of inflation, inflation is more sticky and hence reacts less; but, given the assumed Taylor Rule, policy then responds less aggressively to the TFP shock, i.e. expands demand less. As a result, output also reacts less. Overall, the covariance between inflation and consumption growth is dampened when inflation is low, leading to smaller bond premia.[19]

Finally, to verify that our result is driven by the downward nominal rigidity, in figure 6 we reproduce this experiment when all the parameters are the same except $\psi = 0$. In

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[18] The GIRF of a variable x for a shock of size e at horizon k defined as GIRF(x,s,k,e)=E$_t(x(t+k)|s(t)=s+e)-E_t(x(t+k)|s(t)=s)wheresisthestate.Thisisthecorrectnotionor IRF inanonlinearmodel, andingeneraldependsonthesize(andsign)of theshock$aswell

[19] Here, we show responses of economies with different inflation target; in the appendix, we present the same figure when there are no parameter differences between economies, but simply differences in initial conditions (productivity) that lead to differences in inflation.

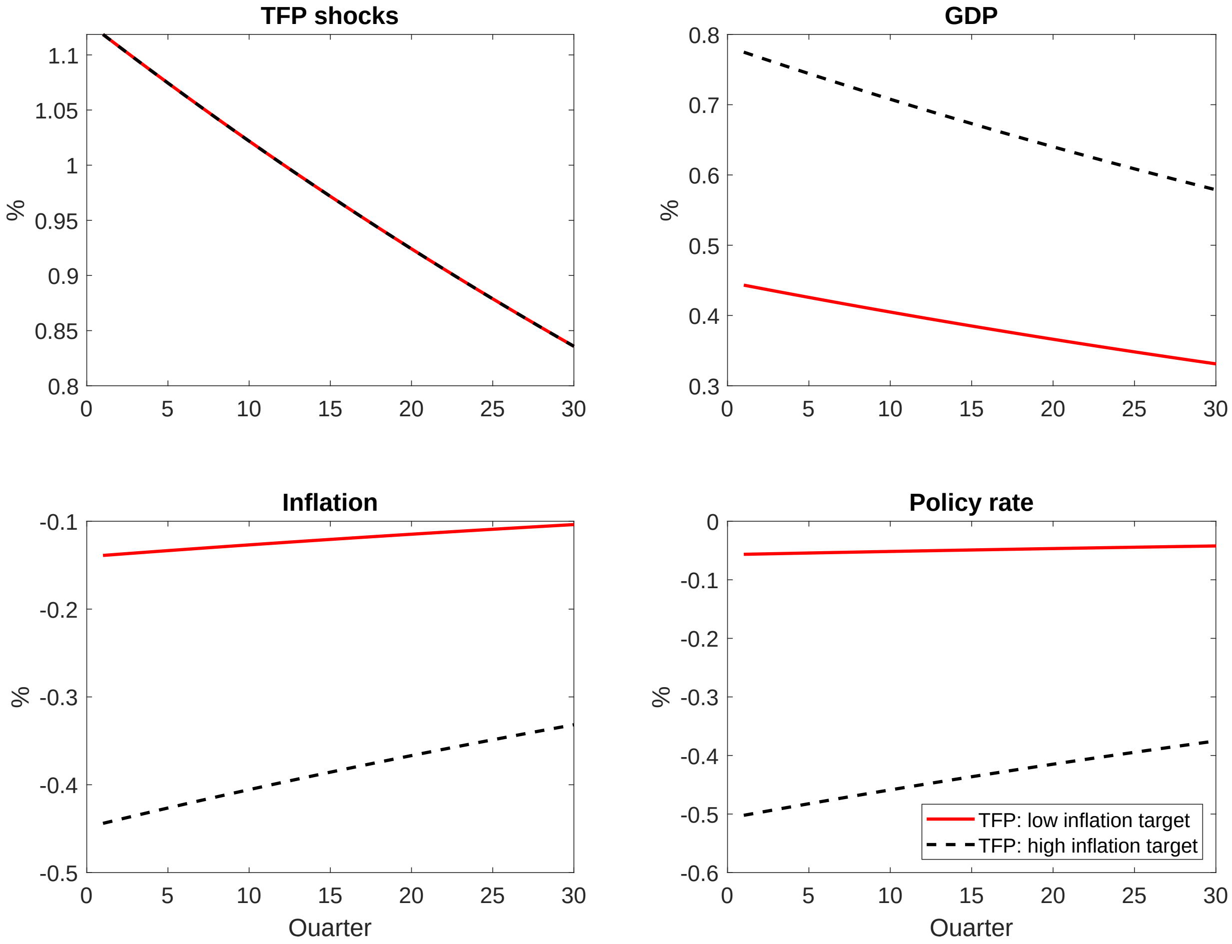

Figure 5: **Generalized impulse response function to a productivity shock. Benchmark model (asymmetric price adjustment costs).**

this case, we recover the traditional quadratic (symmetric) adjustment cost for prices, and the impulse responses are now identical, regardless of the inflation target.

4.3 Moments

Table 4 presents the moments of some key variables for our benchmark calibration. The model undershoots the volatility of GDP.[20] Some of these moments are matched by virtue of the parameter choice, such as the mean of nominal yields, inflation, and the volatility of inflation. But not targeted, and of interest, is the volatility of the long yield, which is not

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[20] Since we have only one shock, we target the volatility of inflation, as explained in the calibration section. Obviously, undershooting output volatility makes it relatively more difficult to generate large and volatile risk premia.

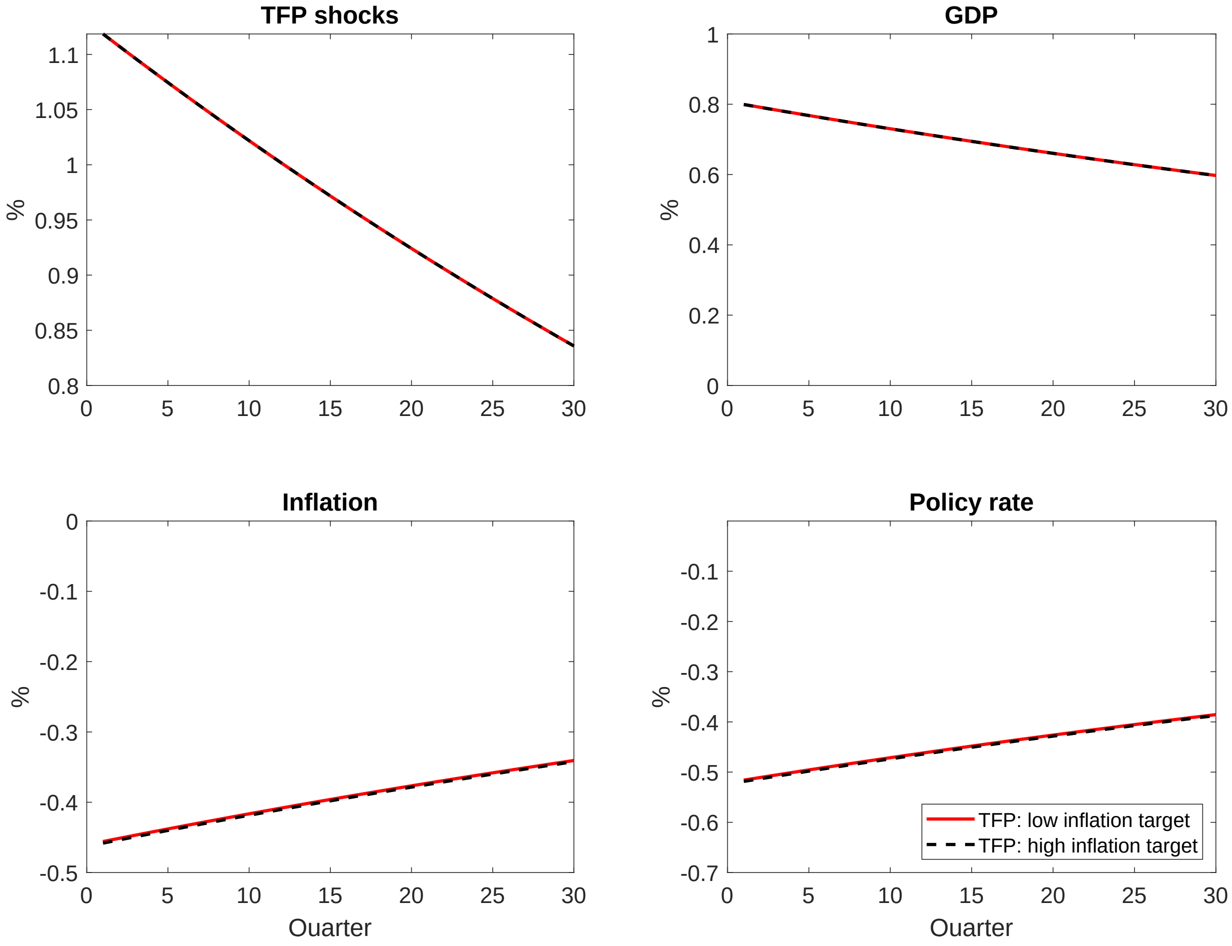

Figure 6: **Generalized impulse response function to a productivity shock. Model with symmetric price adjustment costs.**

	Data		Full sample		$\pi \leq 2\%$	$\pi \geq 4\%$
	Mean	Sd	Mean	Sd	Mean	Mean
$D.lnY$	0.00	3.03	0.00	2.37	0.14	-0.29
π	3.14	1.97	3.14	1.97	1.54	6.03
$y^{n(1)}$	5.63	3.20	5.63	1.97	4.32	8.55
$y^{n(40)}$	7.36	2.97	7.36	2.12	5.37	10.38
$y^{r(1)}$	NaN	NaN	2.37	0.34	2.72	2.37
$y^{r(40)}$	NaN	NaN	2.42	0.19	2.41	2.63
Real term premium	NaN	NaN	0.02	0.21	-0.21	0.29
Nominal term premium	NaN	NaN	1.67	0.68	0.88	2.50

Table 4: Data and model moments. Columns 2 and 3 report the mean and standard deviation from U.S. Data over the sample 1979q4-2008q4. Columns 4 and 5 report the mean and standard deviation for the model. Columns 6 and 7 give the model mean and standard deviation by subsamples. $D.lnY$ denotes the first difference in natural logarithm of output.

too far below the data. This arises because the model generates some significant cyclical variation in term premia. The real term premium is small and stable - because our model has very persistent shocks, making consumption close to a unit root.

As the subsample columns shows, the nominal term premium is much higher when inflation is high than when it is low - owing to the higher volatility of inflation and output. Indeed, the change in the term premium between the subsample with low and high inflation is larger than in the data: a change in the TP of 162bps for 4.5pp change of inflation, or roughly 36bps of TP for one pp of inflation (vs. 15-26bps in the data, as shown in Section 2).

4.4 Effect of Trend Inflation on Macro Dynamics and Risk Premia

We now illustrate how our model can replicate the empirical evidence outlined in Section 2. We take our benchmark model and vary the inflation target Π^* (or, equivalently, the intercept of the Taylor rule R^*), generating changes in average inflation. Figure 7 depicts the 10-year term premium as a function of average inflation, in our model, in the model with symmetric adjustment costs, and in the data. The model broadly reproduces the empirical pattern: higher inflation is associated with higher average term premia. The magnitude of the association is roughly in line with what we measured in the data in table 1: a one percentage point increase in inflation corresponds to about 20bps higher TP.

Figure 9 depicts the six moments shown in Section 2, as a function of average inflation,

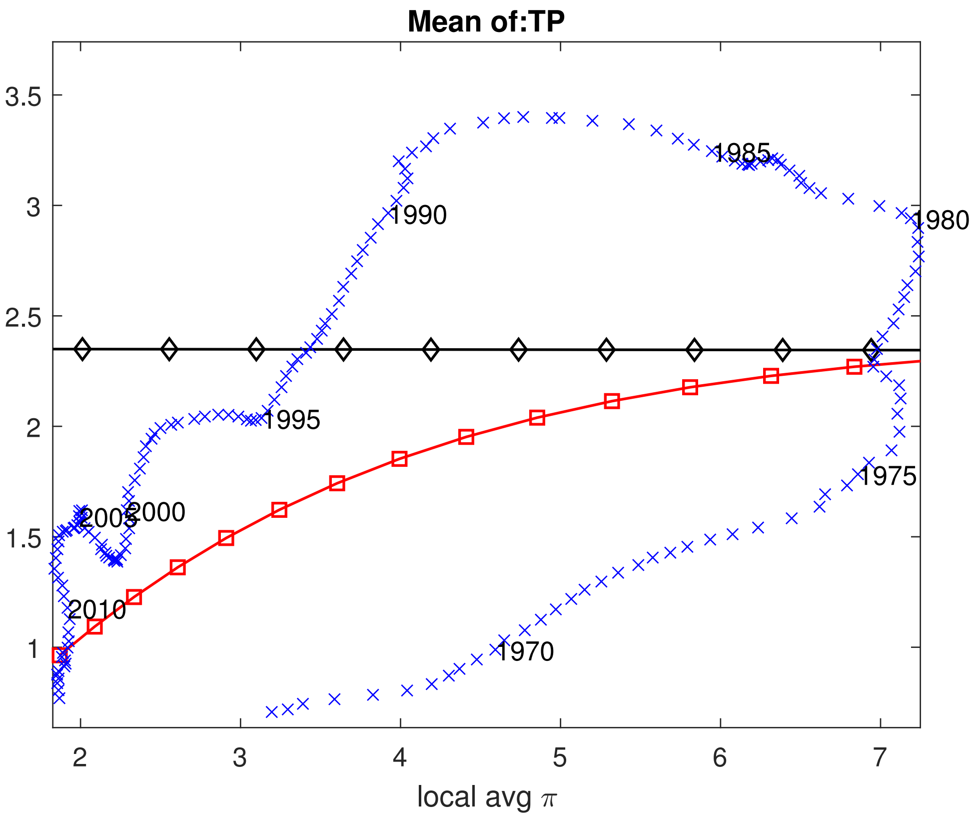

Figure 7: Average 10-y treasury bond premium, as a function of average inflation, in the model (symmetric (black) and asymmetric (red)) and in the data (blue). Data is calculated using the ACM term premium estimate, and using 13-year centered rolling windows, as in Section 2.

in the asymmetric and symmetric model. Figure 8 adds the data for comparison (and removes the symmetric model for legibility).

First, the model with asymmetric rigidities generates substantial variation in all six moments - because of the changes in dynamics that we documented in the earlier section using impulse responses. Second, the symmetric model generates essentially no variation in these models. This shows that our model results are driven by the asymmetry. Third, comparing with the data, we see that the asymmetric model matches qualitatively well, and often quantitatively, the patterns in variation in these moments. Hence, this simple feature can account for a broad range of changes. Table 5 illustrates this quantitatively by calculating the parameters for different values of the inflation target. When the long-run inflation increases from 1.51% to 8.13%, the term premium increases from 75bps to 257bps. In other words, a 1% decrease in the long-run inflation is associated with 27bps decrease in the term premium of the 10-year bonds, which is in line with the 15-26bps we estimated in the data.

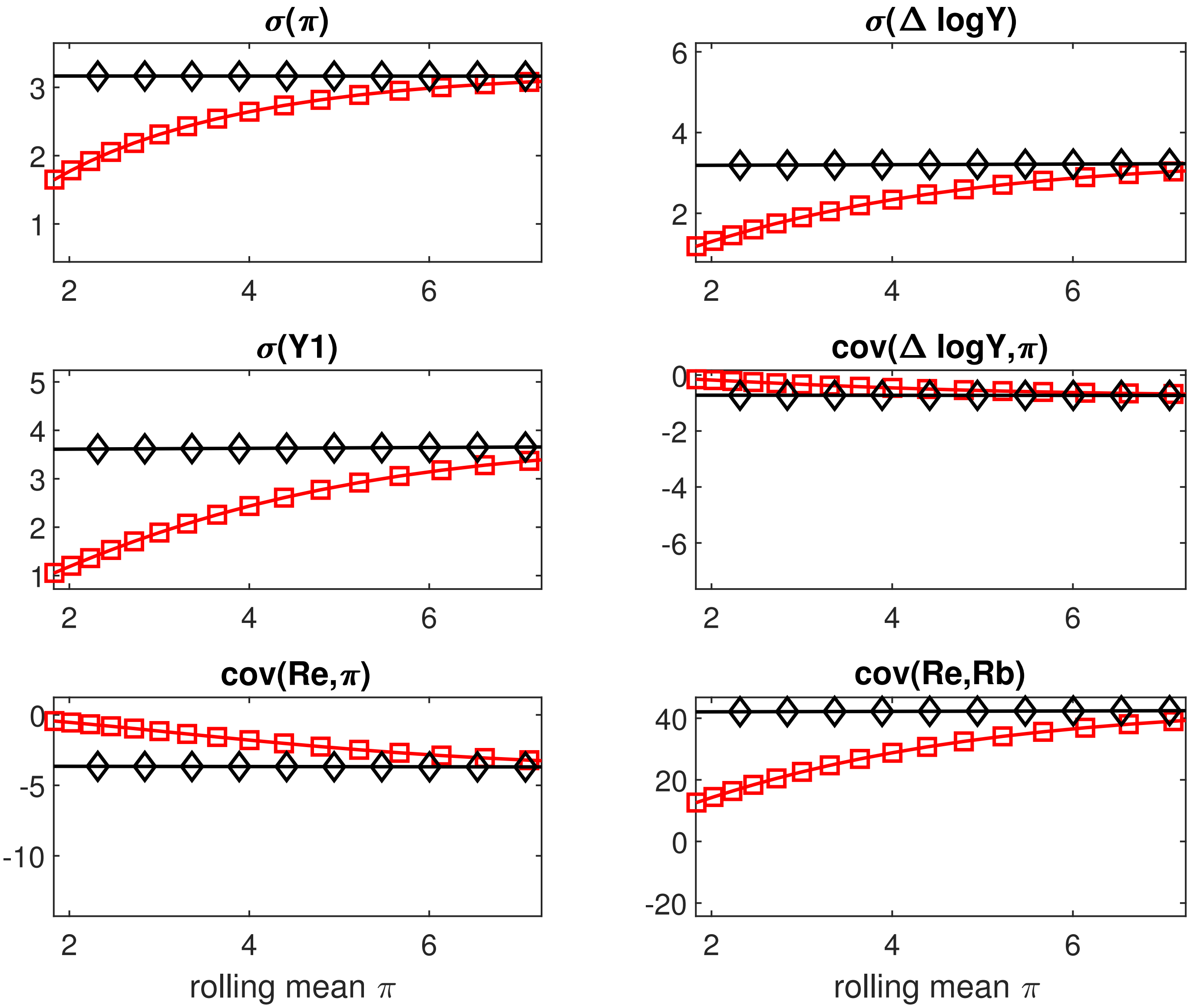

Figure 8: Each panel plots a model moment against the model mean of inflation, together with the data local moment against the local mean of inflation, where both are estimated on a 13-year centered rolling window, as in Section 2. The moments are the volatility of inflation (top left), of GDP growth (top right), of the 3-month T-bill rate (middle left), the covariance of GDP growth and inflation (middle right), the covariance of real equity return and inflation, and the covariance of real equity return with the real 10-year bond return. US quarterly data, 1959-2019; inflation is measured as core CPI.

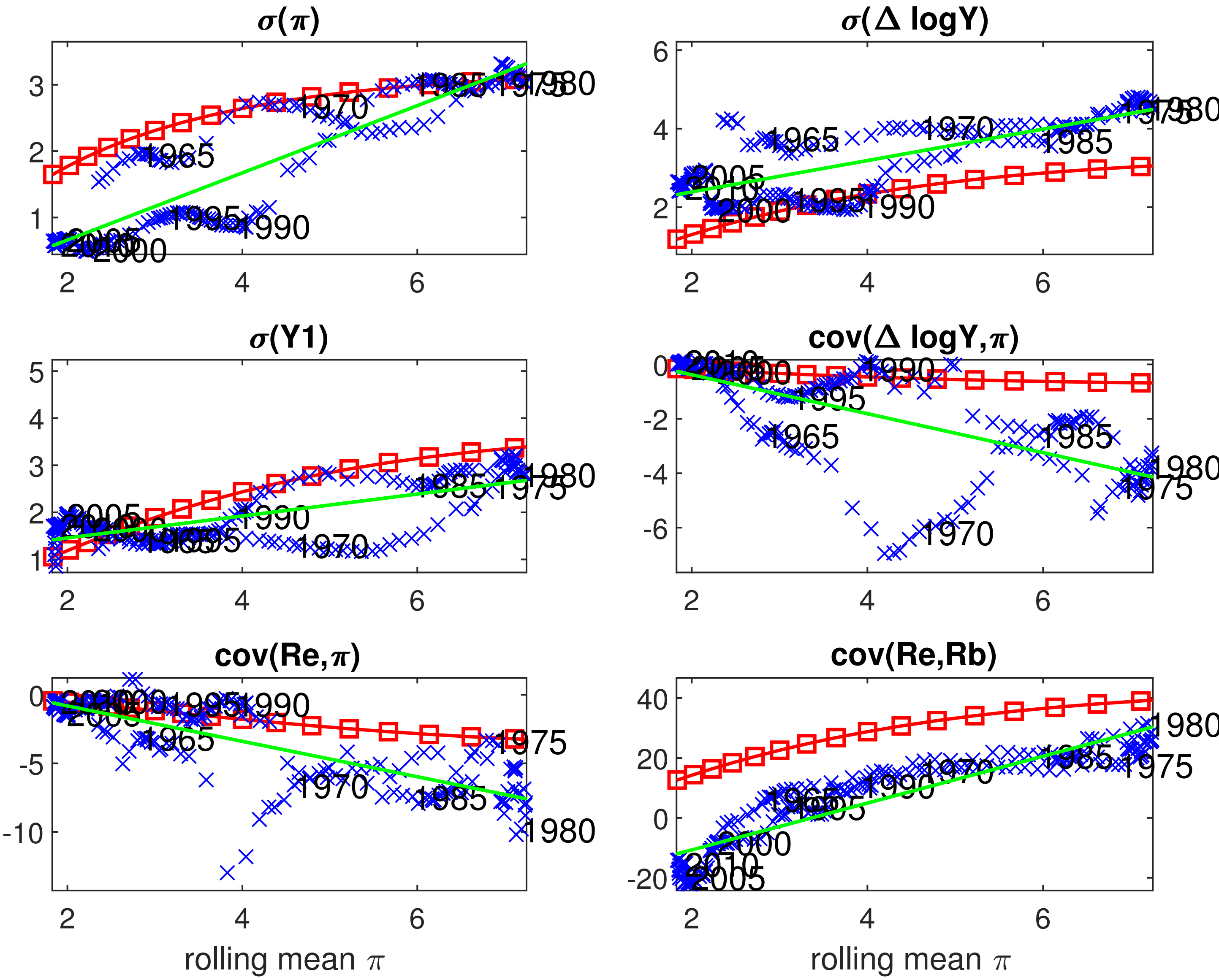

Figure 9: Each panel plots a model moment against the model mean of inflation; the variation here is generated by changes in the inflation target. Asymmetric and Symmetric models. The moments are the volatility of inflation (top left), of GDP growth (top right), of the short-term rate (middle left), the covariance of GDP growth and inflation (middle right), the covariance of real equity return and inflation, and the covariance of real equity return with the real 10-year bond return.

	Data		Benchmark		Varying Taylor Intercepts			
			$R^* = 1.0101$		$R^* = 1.0199$		$R^* = 0.9949$	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std
D.lnY	0.00	3.03	0.00	2.37	0.00	1.39	0.00	3.13
π	3.14	1.97	3.14	1.97	1.51	0.95	8.13	3.13
$y^{n(1)}$	5.63	3.20	5.63	1.97	4.60	0.80	10.19	3.51
$y^{n(40)}$	7.36	2.97	7.36	2.12	5.37	1.15	12.65	2.93
$y^{r(1)}$	NaN	NaN	2.37	0.34	3.03	0.30	1.86	0.39
$y^{r(40)}$	NaN	NaN	2.42	0.19	2.88	0.18	2.18	0.34
Real TP	NaN	NaN	0.02	0.21	-0.15	0.11	0.31	0.08
Nominal TP	NaN	NaN	1.67	0.68	0.75	0.56	2.57	0.21

Table 5: Comparative analysis with inflation target (i.e. Taylor rule intercept).

5 Additional Implications & Robustness

This section first discusses some additional implications of the model, before presenting some comparative statics and robustness.

5.1 Fama-Bliss predictability of bond returns

Tables 6, 7, and 8 show the Fama-Bliss predictability regression (excess bond return at horizon n, in quarters, on the yield spread of maturity n) using the US data, the model with symmetric adjustment costs, and the model with asymmetric adjustment costs, respectively. With asymmetric adjustment costs, the model is able to qualitatively replicate the data, as in table 8. However, this is not the case for the model with symmetric adjustment costs, as in table 7.

Where does this comes from? Intuitively, a negative shock to productivity, that leads inflation to go up, increases the short-term rate, and also increases the long-term rate, because the shock is persistent. The bond premium goes up because inflation goes up. The question is why the term spread goes up -as it needs to in order to generate the Fama-Bliss predictability. There are two reasons why it does. First, if the is transitory enough, the long yield would not move at all - hence, we need highly persistent shocks for the long yield to increase. Second, the increase in the bond premium leads to an increase in the TP which increases the yield - and hence makes the slope increases in response to the negative productivity shock - that is, the curve steepens.

	β	std	R^2
n=8	0.697	0.059	0.060
n=16	0.916	0.123	0.049
n=24	1.152	0.206	0.046
n=32	1.302	0.313	0.038
n=40	1.384	0.443	0.029

Table 6: Fama-Bliss predictability of bond returns using U.S. data.

	β	std	R^2
n=8	-0.073	0.001	0.000
n=16	-0.070	0.001	0.000
n=24	-0.067	0.001	0.000
n=32	-0.064	0.001	0.000
n=40	-0.062	0.001	0.000

Table 7: Fama-Bliss predictability of bond returns in the model with symmetric adjustment costs.

	β	std	R^2
n=8	1.003	0.000	0.103
n=16	1.039	0.000	0.073
n=24	1.046	0.000	0.049
n=32	1.024	0.000	0.032
n=40	0.963	0.000	0.020

Table 8: Fama-Bliss predictability of bond returns in the model with asymmetric adjustment costs.

	Data	Model
GDP	1.55	1.22
	(0.34)	(0.17)
	[4.6]	[7.2]

Table 9: Regression of GDP growth on term spread (8q-1q rates) in the model and in the data.

5.2 The term spread forecasts growth

It is well known that the term spread (negatively) forecasts GDP growth. To evaluate the ability of the model to match this evidence, we run the regression:

$$\log \frac{Y_{t+4}}{Y_t} = \alpha + \beta TS_t^{2y-Tbill} + \varepsilon_t,$$

in the spirit of Engstrom and Sharpe (2018), both in the model and in the data. We find that the model is able to reproduce quantitatively this relationship.

5.3 Asymmetry of macroeconomic variables

We now illustrate that this simple model generates negative skewness in economic activity and positive skewness in inflation, consistent with the data. Figure 10 depicts the histogram of outcomes in the model. The distributions of policy rates and inflation are skewed to the right, while the distribution of output gap is skewed to the left.

5.4 Asymmetric Impulse Responses

We illustrate here that the model produces asymmetric responses to positive and negative shocks. (In the appendix, we verify that these asymmetric responses disappear when the adjustment cost is symmetric.)

Figure 11 shows impulse responses to a three-standard deviation of TFP innovations shock when the shock is negative (red solid line) vs. positive (black dashed line). The responses to positive shocks are displayed with the reverse sign. Again, the economy is initially at the deterministic steady state. When hit by a negative TFP shock, firms respond more aggressively than when they are hit by a positive shock. Under a negative TFP shock, the marginal cost increases and firms would like to raise their prices. On the contrary, firms would lower their prices under a positive TFP. However, the magnitude of price increase is about two times larger than that of price cut. This happens due to

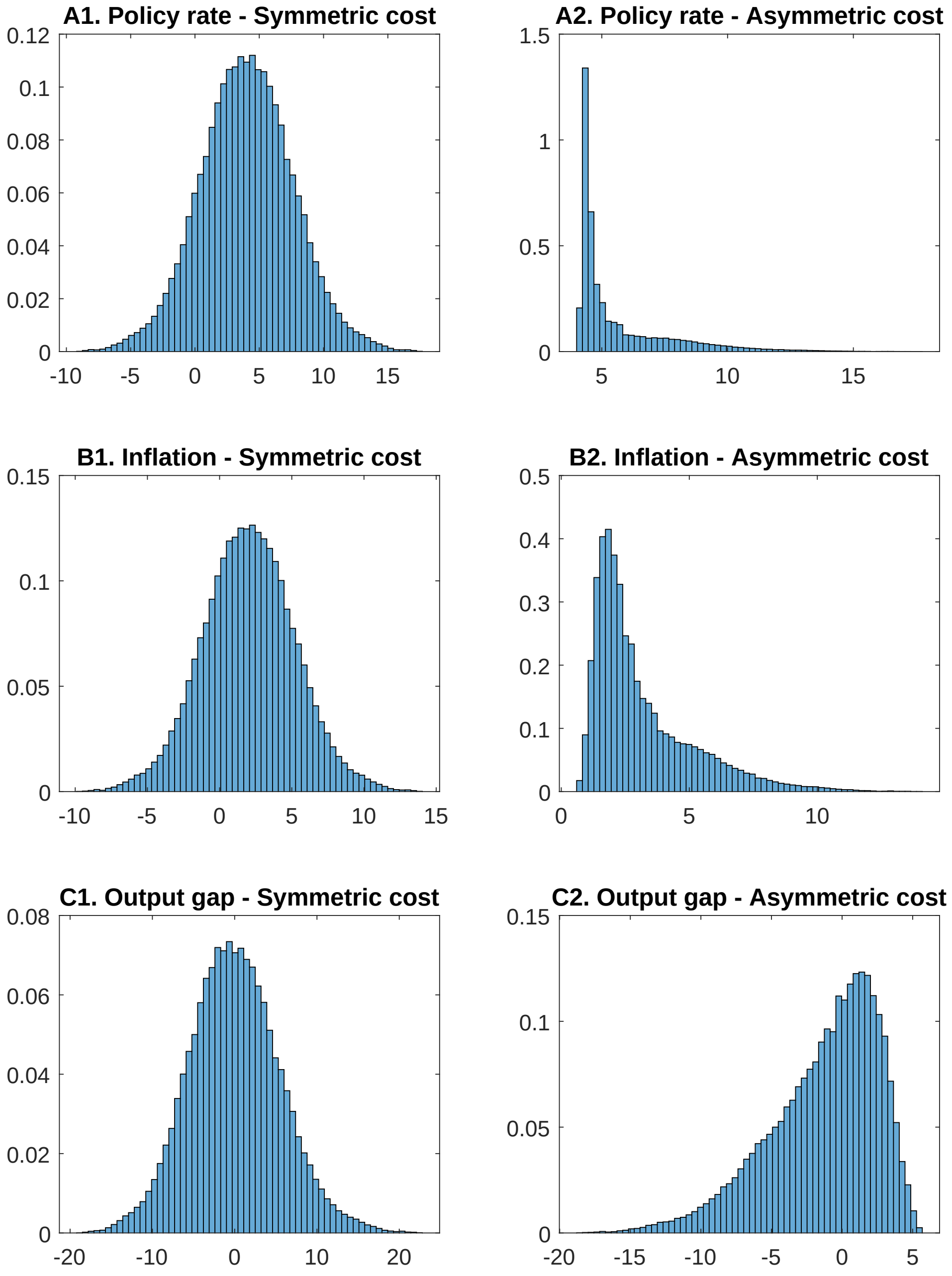

Figure 10: Probability density functions of macroeconomic variables based on 100,000 periods simulation.

downward nominal rigidities embedded in our model prevent firms from cutting the prices. This asymmetry occurs to GDP and consumption too.

The asymmetric responses implies that the covariance between inflation and consumption growth is more negative under a adverse TFP shock than under a positive TFP shock. This means that the inflation term premium is more positive under a negative TFP shock than under positive TFP shock, leading to the distribution of inflation term premium being skewed to the right.

Overall, the inflation term premium is smaller in the asymmetric case than in the symmetric case because the covariance between inflation and consumption growth is less negative on average. In addition, in the asymmetric case the inflation term premium is more skewed to the right. Thus, the slope of the yield curve is steeper in the case of downward nominal rigidities.

5.5 Comparative statics

Finally, we illustrate further the workings of the model with some comparative statics.

Asymmetry versus symmetry Table 10 compares the symmetric and asymmetric models.

Table 10 shows that in the symmetric world, 1% decrease in inflation is associated with only 0.5bps decrease in the term premium, which is extremely small compared with 36bps in the case of asymmetry. In the next subsection we show that when we raise the asymmetry level, the change in term premium becomes bigger.

The role of asymmetry due to downward nominal rigidity Table 11 shows the effect of varying the asymmetry parameter ψ.

As seen from this table, the higher level of asymmetry, the larger the decrease in term premia associated with 1% decrease in inflation across the subsamples. Specifically, the decrease is 36bps in the benchmark with $\psi = 884$, while it is 56bps in the case $\psi = 1500$. The decrease is reduced to 22bps when we lower the value of asymmetry to 500.

The role of monetary policy Finally, we illustrate the role of monetary policy - and in particular, the effect of more aggressive inflation response - on risk premia and their volatility. Clearly, if the central bank is able to stabilize inflation around its target, there won't be much low or high inflation that trigger the working of downward nominal rigidities. Figure 12 shows the distributions of inflation, policy rates, and output gap

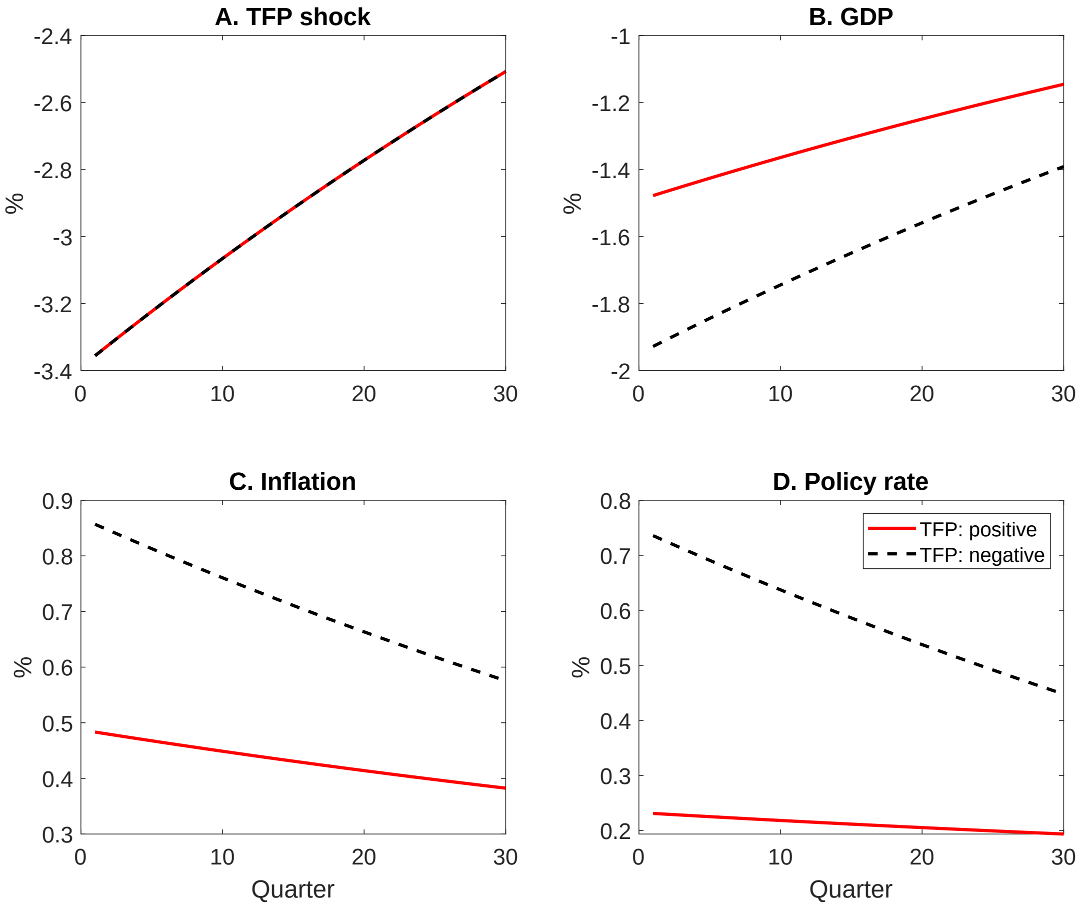

Figure 11: **Impulse response functions to positive and negative shocks with asymmetric price adjustment costs.** Impulse response to a three-standard deviation of productivity innovations shock when the shock is positive (red solid line) vs. negative (black dashed line). The responses to positive shocks are displayed with the reverse sign. The economy is initially at the deterministic steady state. The case of asymmetric adjustment costs.

A. All observations

	Data		Symmetric		Benchmark	
	Mean	Std	Mean	Std	Mean	Std
D.lnY	0.00	3.03	-0.00	3.68	-0.00	3.03
π	3.14	1.97	2.36	2.95	3.12	1.91
$y^{n(1)}$	5.63	3.20	4.60	3.47	5.71	2.05
$y^{n(40)}$	7.36	2.97	6.94	2.82	7.43	2.09
$y^{r(1)}$	NaN	NaN	2.14	0.66	2.55	0.44
$y^{r(40)}$	NaN	NaN	2.51	0.43	2.68	0.25
Real TP	NaN	NaN	0.37	0.00	0.10	0.19
Nominal TP	NaN	NaN	2.35	0.02	1.58	0.60

B. Subsample

	Data		Symmetric		Benchmark	
	Mean	Std	$\pi < 2\%$	$\pi > 4\%$	$\pi < 2\%$	$\pi > 4\%$
D.lnY	0.00	3.03	0.18	-0.28	0.14	-0.29
π	3.14	1.97	-0.50	5.97	1.54	6.03
$y^{n(1)}$	5.63	3.20	1.17	8.50	4.32	8.55
$y^{n(40)}$	7.36	2.97	4.28	10.31	5.37	10.38
$y^{r(1)}$	NaN	NaN	1.50	2.38	2.72	2.37
$y^{r(40)}$	NaN	NaN	1.90	2.63	2.41	2.63
Real TP	NaN	NaN	0.34	0.35	-0.21	0.29
Nominal TP	NaN	NaN	2.62	2.65	0.88	2.50

Table 10: Asymmetry versus symmetry. *D.lnY* is the first difference in natural logarithm of output.

A. All observations

	Data		Benchmark		$\psi = 500$		$\psi = 1500$	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std
D.lnY	0.00	3.03	0.00	2.37	0.00	2.58	0.00	2.21
π	3.14	1.97	3.14	1.97	2.78	2.28	3.44	1.75
$y^{n(1)}$	5.63	3.20	5.63	1.97	5.13	2.36	6.04	1.73
$y^{n(40)}$	7.36	2.97	7.36	2.12	7.12	2.36	7.57	1.95
$y^{r(1)}$	NaN	NaN	2.37	0.34	2.22	0.25	2.50	0.43
$y^{r(40)}$	NaN	NaN	2.42	0.19	2.34	0.20	2.48	0.19
Real TP	NaN	NaN	0.02	0.21	0.10	0.17	-0.04	0.23
Nominal TP	NaN	NaN	1.67	0.68	1.94	0.55	1.46	0.76

B. Subsample

	Data		Benchmark		$\psi = 500$		$\psi = 1500$	
	Mean	Std	$\pi < 2\%$	$\pi > 4\%$	$\pi < 2\%$	$\pi > 4\%$	$\pi < 2\%$	$\pi > 4\%$
D.lnY	0.00	3.03	0.14	-0.29	0.16	-0.28	0.08	-0.30
π	3.14	1.97	1.54	6.03	0.93	5.98	1.91	6.08
$y^{n(1)}$	5.63	3.20	4.32	8.55	3.30	8.50	5.28	8.61
$y^{n(40)}$	7.36	2.97	5.37	10.38	5.11	10.33	5.34	10.43
$y^{r(1)}$	NaN	NaN	2.72	2.37	2.28	2.36	3.33	2.37
$y^{r(40)}$	NaN	NaN	2.41	2.63	2.22	2.63	2.90	2.64
Real TP	NaN	NaN	-0.21	0.29	-0.06	0.31	-0.29	0.27
Nominal TP	NaN	NaN	0.88	2.50	1.44	2.55	0.12	2.44

Table 11: Comparative analysis with the asymmetry parameter. $D.lnY$ is the first difference in natural logarithm of output.

	GDP	Inflation
β_z	0.100	-0.028
	(0.029)	(0.023)
	[3.4]	[1.2]
γ	**0.024**	**-0.021**
	0.010	0.008
	[2.4]	[2.8]

when monetary policy is more aggressive toward stabilizing inflation, i.e. the coefficient on inflation gap in the Taylor rule is raised to 5 from 2 as in the benchmark. It can be seen from the figure that the skewness of the distributions of inflation and output gap almost disappear.

6 Time-varying impulse responses

Finally, in this section, we provide some more direct evidence in favor of the key mechanism of the paper, namely state-dependent IRF. The key prediction is that when inflation is higher, output reacts more positively, and inflation more negatively, to a positive TFP shock. To test this, we estimate simple local projection of an outcome variable y on TFP growth Z and an interaction term with the level of inflation π_t:

$$y_{t+4} = \alpha + \sum_{i=1}^{L} \beta_i y_{t-i} + \beta_z Z_t + \beta_\pi \pi_t + \gamma Z_t \pi_t + \varepsilon_t$$

where y is log GDP or log (core) PCE index, and Z_t is utilization adjusted (Fernald) TFP growth, i.e.

$$Z_t = \log(TFP_t / TFP_{t-4})$$

and finally π_t is (annualized) inflation over the past 2 years - to capture the concept of "prevailing" (or "underlying") inflation. We estimate this equation on the sample 1953q1:2019q4 and obtain the following estimates:[21]

The first row shows that higher TFP growth increases GDP and reduces inflation; however, the effect on GDP is fairly small and the effect on inflation is small and insignificant. More interesting, the fourth row shows that the interaction term for output is positive, statistically significant, and economically meaningful: going from 0% to 4% annual inflation doubles the coefficient on output. Moreover, the coefficient on inflation is negative, and

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[21] These equations include a quadratic time trend, which does not affect estimates but reduces standard errors; SEs are Newey-West with 12 lags.

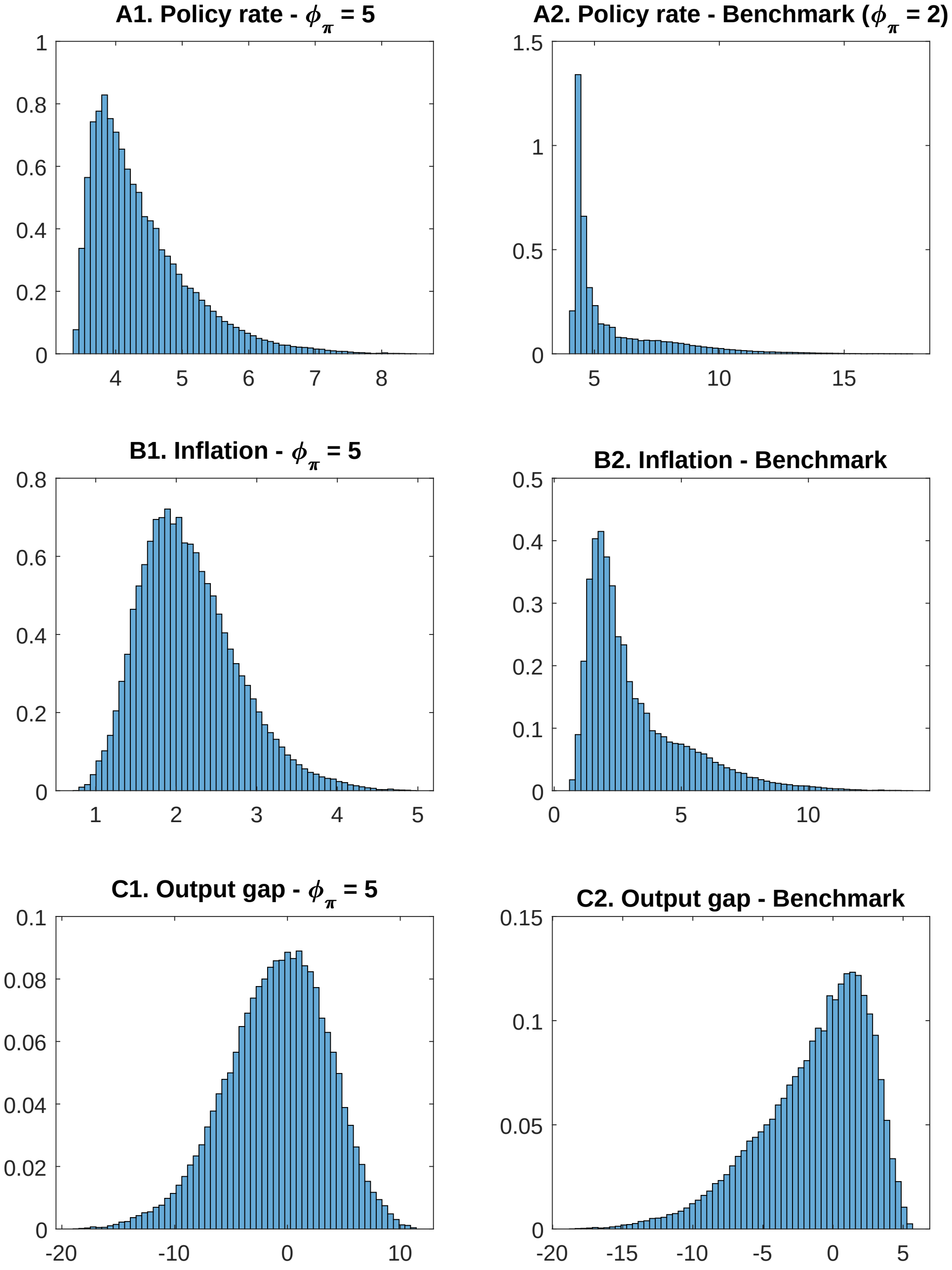

Figure 12: Probability density functions of macroeconomic variables with more inflation-stabilizing monetary policy, i.e. $\phi_\pi = 5$. The result is computed based 100,000 periods simulation.

economically and statistically significant: a 1% TFP increase doubles the effect inflation. Qualitatively at least, these results are consistent with our economic mechanism.

7 Conclusion

This paper develops a production asset pricing model with downward nominal rigidities, and shows it can explain trend and cyclical changes in term premia and other macro-finance moments. To be sure, other possible explanations for some of these facts exist, and indeed are complementary, and future work should try and disentangle these empirically. From a theoretical point of view, the current paper has focused on how macroeconomic dynamics generate term premia, but a natural next step is to study how term premia affect the macroeconomy. This would likely require abandoning the representative agent framework, and would allow studying the new trade-offs that monetary policy confronts when it has an impact on long-term bond yields.

References

Abbritti, M., Fahr, S., 2013. Downward wage rigidity and business cycle asymmetries. Journal of Monetary Economics 60 (7), 871–886.

Adrian, T., Crump, R. K., Moench, E., 2013a. Pricing the term structure with linear regressions. Journal of Financial Economics 110(1), 110–138.

Adrian, T., Crump, R. K., Moench, E., 2013b. Pricing the term structure with linear regressions. Journal of Financial Economics 110 (1), 110–138.

Ang, A., Bekaert, G., Wei, M., 2008. The term structure of real rates and expected inflation. Journal of Finance 63 (2), 797–849.

Arouba, B., Cuba-Borda, P., Schorfheide, F., 2018. Macroeconomic dynamics near the zlb: A tale of two countries. The Review of Economic Studies 85 (1), 87–118.

Ascari, G., 2004. Staggered prices and trend inflation: some nuisances. Review of Economic dynamics 7 (3), 642–667.

Ascari, G., Rossi, L., 2012. Trend inflation and firms price-setting: Rotemberg versus calvo. The Economic Journal 122 (563), 1115–1141.

Ascari, G., Sbordone, A. M., 2014. The macroeconomics of trend inflation. Journal of Economic Literature 52 (3), 679–739.

Bansal, R., Shaliastovich, I., 2013. A long-run risks explanation of predictability puzzles in bond and currency markets. The Review of Financial Studies 26(1), 1–33.

Basu, S., House, C. L., 2016. Allocative and remitted wages: New facts and challenges for keynesian models. In: Handbook of macroeconomics. Vol. 2. Elsevier, pp. 297–354.

Belo, F., Lin, X., Bazdresch, S., 2014. Labor hiring, investment, and stock return predictability in the cross section. Journal of Political Economy 122 (1), 129–177.

Benigno, P., Antonio Ricci, L., 2011. The inflation-output trade-off with downward wage rigidities. American Economic Review 101 (4), 1436–1466.

Bernanke, B. S., 2022. 21st Century Monetary Policy: The Federal Reserve from the Great Inflation to COVID-19. WW Norton & Company.

Bilal, M., 2017. Zeroing in: Asset pricing near the zero lower bound. Available at SSRN 2897926.

Branger, N., Schlag, C., Shaliastovich, I., Song, D., 2016. Macroeconomic bond risks at the zero lower bound. Available at SSRN 2820207.

Campbell, J., Pflueger, C., Viceira, L. M., 2020. Macroeconomic drivers of bond and equity risks",. Journal of Political Economy 128, 3148–3185.

Campbell, J. Y., Shiller, R. J., 1991. Yield spreads and interest rate movements: A bird's eye view. The Review of Economic Studies 58 (3), 495–514.

Campbell, J. Y., Sunderam, A., Viceira, L. M., 2009. Inflation bets or deflation hedges? the changing risks of nominal bonds. National Bureau of Economic Research Working Paper.

Christensen, J. H., Diebold, F. X., Rudebusch, G. D., 2011. The affine arbitrage-free class of nelson–siegel term structure models. Journal of Econometrics 164 (1), 4–20.

Christiano, L., Eichenbaum, M., Rebelo, S., 2010. When is the government spending multiplier is large? Northwestern University Working Paper.

Daly, M. C., Hobijn, B., 2014. Downward nominal wage rigidities bend the phillips curve. Journal of Money, Credit and Banking 46 (S2), 51–93.

D'Amico, S., Kim, D. H., Wei, M., 2018. Tips from tips: the informational content of treasury inflation-protected security prices. Journal of Financial and Quantitative Analysis 53 (1), 395–436.

Datta, D., Johannsen, B. K., Kwon, H., Vigfusson, R. J., 2018. Oil, equities, and the zero lower bound. FEDS Working paper.

David, A., Veronesi, P., 2013. What ties return volatilities to price valuations and fundamentals?",. Journal of Political Economy 121 (4), 682–746.

Dew-Becker, I., 2022. Tail risk in production networks. Tech. rep., National Bureau of Economic Research.

Dew-Becker, I., Tahbaz-Salehi, A., Vedolin, A., 2021. Skewness and time-varying second moments in a nonlinear production network: theory and evidence. Tech. rep., National Bureau of Economic Research.

Donangelo, A., 2014. Labor mobility: Implications for asset pricing. The Journal of Finance 69 (3), 1321–1346.

Donangelo, A., Gourio, F., Kehrig, M., Palacios, M., 2019. The cross-section of labor leverage and equity returns. Journal of Financial Economics 132 (2), 497–518.

Dupraz, S., Nakamura, E., Steinsson, J., 2019. A plucking model of business cycles. Tech. rep., National Bureau of Economic Research.

Elsby, M. W., Solon, G., 2019. How prevalent is downward rigidity in nominal wages? international evidence from payroll records and pay slips. Journal of Economic Perspectives 33 (3), 185–201.

Epstein, L. G., Zin, S. E., 1989. Substitution, risk aversion, and the temporal behavior of consumption and asset returns: A theoretical framework. Econometrica 57(4), 937–969.

Fama, E. F., Bliss, R. R., 1987. The information in long-maturity forward rates. The American Economic Review, 680–692.

Favilukis, J., Lin, X., 2016. Wage rigidity: A quantitative solution to several asset pricing puzzles. The Review of Financial Studies 29 (1), 148–192.

Favilukis, J., Lin, X., Zhao, X., 2020. The elephant in the room: The impact of labor obligations on credit markets. American Economic Review 110 (6), 1673–1712.

Fernandez-Villaverde, J., Gordon, G., Guerron-Quintana, P., Rubio-Ramirez, J., 2015. Nonlinear adventures at the zero lower bound. Journal of Economic Dynamics and Control 57, 182 –204.

Friedman, M., 1977. Nobel lecture: inflation and unemployment. Journal of political economy 85 (3), 451–472.

Gali, J., 2008. Monetary Policy, Inflation, and the Business Cycle: An Introduction to the New Keynesian Framework. Princeton University Press.

Gourio, F., Ngo, P. V., 2020. Risk premia at the zlb: A macroeconomic interpretation. FRB of Chicago Working Paper No. WP-2020-01.

Grigsby, J., Hurst, E., Yildirmaz, A., 2021. Aggregate nominal wage adjustments: New evidence from administrative payroll data. American Economic Review 111 (2), 428–71.

Gust, C., Herbst, E. Lopez-Salido, D., Smith, M., 2017. The emperical implications of the interest-rate lower bound. American Economic Review 107(7), 1971–2006.

Hazell, J., Taska, B., 2020. Downward rigidity in the wage for new hires. Available at SSRN 3728939.

Hordahl, P., Tristani, O., 2014. Inflation risk premia in the euro area and the united states. International Journal of Central Banking 2014(3), 1–47.

Ireland, N. P., 1997. A small, structural, quarterly model for monetary policy evaluation. Carnegie-Rochester Conference Series on Public Policy 47, 83–108.

Jo, Y. J., Zubairy, S., 2022. State dependent government spending multipliers: Downward nominal wage rigidity and sources of business cycle fluctuations. Tech. rep., National Bureau of Economic Research.

Kahn, S., 1997. Evidence of nominal wage stickiness from microdata. The American Economic Review 87 (5), 993–1008.

Keynes, J. M., 1936. The General Theory of Employment, Interest and Money. Macmillan.

Kim, D. H., Wright, J. H., 2005. An arbitrage-free three-factor term structure model and the recent behavior of long-term yields and distant-horizon forward rates.

Kim, J., Ruge-Murcia, F. J., 2009. How much inflation is necessary to grease the wheels? Journal of Monetary Economics 56, 365–377.

Klenow, P. J., Malin, B. A., 2010. Microeconomic evidence on price-setting. In: Handbook of monetary economics. Vol. 3. Elsevier, pp. 231–284.

Kurmann, A., McEntarfer, E., 2019. Downward nominal wage rigidity in the united states: new evidence from worker-firm linked data. Drexel University School of Economics Working Paper Series WP 1.

Li, E., Palomino, F., 2014. Nominal rigidities, asset returns, and monetary policy. Journal of Monetary Economics 66, 210–225.

Miao, J., Ngo, P., 2016. Does calvo meet rotemberg at the zero lower bound? Working Paper.

Nakamura, G., Steinsson, J., 2008. Five facts about prices: A reevaluation of menu cost models. Quarterly Journal of Economics 123(4), 1415–1464.

Nakata, T., Tanaka, H., 2016. Equilibrium yield curves and the zero lower bound. Working Paper, Federal Reserve Board.

Neftci, S. N., 1984. Are economic time series asymmetric over the business cycle? Journal of political economy 92 (2), 307–328.

Ngo, V. P., 2018. The risk of hitting the zero lower bound and the optimal inflation target. Macroeconomic Dynamics (Published online by Cambridge University Press: 02 May 2017) 22 (2), 402–425.

Palomino, F., 2012. Bond risk premiums and optimal monetary policy. Review of Economic Dynamics 15(1), 19–40.

Peltzman, S., 2000. Prices rise faster than they fall. Journal of Political Economy 108(3), 466–502.

Pflueger, C., Rinaldi, G., 2022. Why does the fed move markets so much? a model of monetary policy and time-varying risk aversion. Journal of Financial Economics 146 (1), 71–89.

Pflueger, C. E., 2022. What do treasury bond risks say about supply and demand shocks? University of Chicago, Becker Friedman Institute for Economics Working Paper (102).

Piazzesi, M., Schneider, M., 2006. Equilibrium yield curves. NBER Working Paper.

Rotemberg, J., 1982. Sticky prices in the united states. Journal of Political Economy 90, 1187–211.

Roussellet, G., 2018. The term structure of macroeconomic risks at the zero lower bound. Available at SSRN 2863271.

Rudebusch, G., Swanson, E., 2008. Examining the bond premium puzzle with a dsge model. Journal of Monetary Economics 55, S111–S126.

Rudebusch, G., Swanson, E., 2012. The bond premium in a dsge model with long-run real and nominal risks. American Economic Journal: Macroeconomics 4(1), 105–143.

Schmitt-Grohé, S., Uribe, M., 2016. Downward nominal wage rigidity, currency pegs, and involuntary unemployment. Journal of Political Economy 124 (5), 1466–1514.

Song, D., 2017. Bond market exposures to macroeconomic and monetary policy risks. The Review of Financial Studies 30 (8), 2761–2817.

Swanson, E., 2015a. A macroeconomic model of equities and real, nominal, and defaultable debt. Working Paper, UC Irvine.

Swanson, E., 2015b. Risk aversion, risk premia, and the labor margin with generalized recursive preferences. Working Paper, Federal Reserve Bank of San Francisco.

Taylor, B., 1993. Discretion versus policy rules in practice. Carnegie-Rochester Conference Series on Public Policy 39, 195–214.

Tobin, J., 1972. Inflation and employment. American Economic Review 62, 1–18.

Weber, M., 2015. Nominal rigidities and asset pricing. Working Paper, University of Chicago.

Weil, P., 1990. Nonexpected utility in macroeconomics. The Quarterly Journal of Economics 105 (1), 29–42.

Woodford, M., 2003. Interest and Prices: Foundations of a Theory of Monetary Policy. Princeton University Press.

Wright, J. H., 2011. Term premia and inflation uncertainty: Empirical evidence from an international panel dataset. American Economic Review 101 (4), 1514–34.