Risk Premia at the ZLB: a Macroeconomic Interpretation[*]

François Gourio[†] and Phuong Ngo[‡]

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Abstract

Historically, inflation is associated with low stock returns, leading investors to fear inflation. We document that this correlation changes after 2008: inflation is now associated with high stock returns. We interpret this as a change in the conditional covariance of (news about) economic activity and inflation. We then show how the zero lower bound (ZLB) on nominal interest rates can explain this change of covariance owing to the changing propagation mechanisms at the ZLB. This has important implications for asset prices since covariances determine risk premia. A fairly standard New Keynesian macroeconomic model can generates positive term premia and inflation risk in normal times (far from the zero lower bound), but these premia fall as the economy becomes closer to the ZLB.

1 Introductions

The relation between inflation and economic activity is controversial, as illustrated by the widespread debate on the empirical relevance of the Phillips curve. The purpose of this paper is to use financial markets data to shed light on this relation, and to study the implications of this relation for asset pricing. In particular, we focus on the recent period in the United States when the zero lower bound (ZLB) constrained monetary policy. Standard macroeconomic models suggest that the response to aggregate shocks is different when the ZLB binds. Demand shocks may have little effect on inflation or economic activity if the ZLB does not bind because the central bank can offset demand fluctuations by changing the interest rate. But the same demand shocks may have large effects if the ZLB binds and the central bank cannot respond.[1] This change in the response to shocks affects the covariance of marginal utility and inflation and consequently the inflation risk premium - the price investors are willing to pay to avoid bearing inflation risk.

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[†] Federal Reserve Bank of Chicago; Email: francois.gourio@chi.frb.org.

[‡] Cleveland Sate University; Email p.ngo@csuohio.edu.

[1] Similarly, supply shocks may have smaller effects on output if the ZLB binds, and possibly larger (opposite sign) effects on inflation, because monetary policy cannot accomodate them. As argued by Eggertsson (2012), a positive supply shocks may even be recessionary at the ZLB.

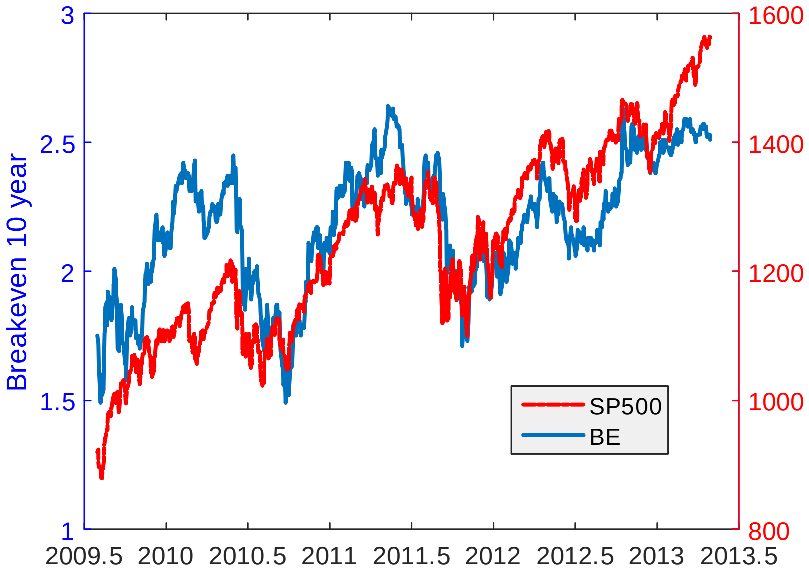

Figure 1: 10-year inflation breakeven (left-scale) and SP500 (right-scale): 2009:7:2013:5.

The first contribution of the paper is to study the empirical relation between stock prices and inflation. We document that there has been a significant change in the response of stock prices to inflation in the United States after 2008. Historically, high inflation is associated with low stock returns, as documented in a long literature dating back at least to Fama and Schwert (1977)). But since 2008, stock prices appear to react positively to inflation. As a simple illustration, figure 1 depicts the strong correlation between stock prices and the 10-year breakeven (the difference between the yield of a 10 year nominal Treasury bond and a 10 year indexed Treasury bond, which is often used as a proxy for expected inflation) between 2009 and 2013. During this period, increases in stock prices - which typically reflected positive assessment of the economic recovery - were also associated with increases in inflation breakevens.

We demonstrate the change in the association of stock prices and inflation using three different sources: (i) correlations between the stock market and measures of inflation compensation (inflation breakevens, inflation swaps, or a portfolio of individual stocks constructed to mimic inflation); and (ii) the response of stock prices to inflation data releases during short windows; (iii) the response of monthly stock prices to monthly inflation. These facts are new to the best of our knowledge, and they are also consistent with the ZLB mechanism outlined above.

We interpret this change in correlation as reflecting a change in the conditional covariance of inflation and news about the state of the economy, or to simplify consumption growth $Cov_t(\Delta c_{t+1}, \pi_{t+1})$.[2] This has important implications for the pricing of inflation risk, because (in a canonical consumption based model) this pricing depends on the covariance of inflation and consumption growth. The change in the correlation suggests that the inflation risk premium is low or even negative, which is broadly consistent with other indirect measures such as affine term structure models estimates.[3] More generally, in a world where supply shocks dominate, the covariance is strongly negative, investors fear inflation, and the risk premium for bearing inflation risk is positive. But in a world where demand shocks dominate (e.g. because of the ZLB), this covariance is positive, and the inflation risk premium may be negative. If the stock market reflects expectation of future output, and breakevens expectations of future inflation, then the covariance of stock prices and breakevens is a proxy for this covariance.[4]

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[2] Obviously, stock prices are at best indirect measures of *current* economic activity, but they are likely good measures of the *future* state of the economy, which are important for marginal utility.

The second contribution of our paper is to demonstrate theoretically how the covariance of economic activity and inflation *endogenously* changes depending on whether the ZLB binds. We solve a fairly standard New Keynesian dynamic stochastic general equilibrium (DSGE) model with high risk aversion, taking the ZLB into consideration, using nonlinear methods. As predicted by the simple intuition that demand (supply) shocks are amplified (weakened) at the ZLB, the As a result, the model generates positive inflation and term premia in normal times (far from the ZLB), but lower inflation and term premia at the ZLB.

Overall, the paper connects the recent behavior of asset prices with a leading macroeconomic framework, and connects well-known recent observations about financial markets – nominal bonds appear to be good hedges – with macroeconomic theory: bonds are good hedges because demand shocks matter more at the ZLB. This implies lower term premia, hence the model help explains why long-term interest rates have remained so low since 2008.

Given the importance of long-term interest rates, which are a reference borrowing cost, understanding their movements is of primary interest for research and policy. The reduction in term and inflation premia also has some important "practical" consequences. First, there is a wide-ranging debate about the sources of the decline of interest rates, and to what extent this decline will last. Our model suggests that an upturn in the economy or in inflation may lead to a significant increase in interest rates because these risk premia change as the ZLB becomes less of a constraint. Second, economists and policymakers often use inflation compensation (i.e., inflation swaps or inflation breakevens) as a measure of expected inflation. It is well understood that inflation compensation may differ from expected inflation due to risk or liquidity premia; but the magnitude and even the sign of this adjustment are controversial. Our model argues that breakevens *underestimate* expected inflation when the economy operates close to the ZLB, but *overestimate* expected inflation when the economy is far from the ZLB. Third, our analysis is an indirect test of the widely-used ZLB New Keynesian macroeconomic model.

The paper is organized as follows. The rest of the introduction reviews briefly the related literature. Section 2 studies a simple example that illustrates how the covariance of macroeconomic variables affects the inflation risk premium and breakeven rates. Section 3 presents reduced form evidence that the link between the inflation and risky assets has changed since 2008. Section 4 introduces a stylized DSGE model. Section 5 provides some preliminary quantitative results. Section 6 concludes.

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[3] For some prominent models, see Kim and Wright (2005), Adrian, Crump and Moench (2013), D'Amico, Kim and Wei (2010), Ajello, Benzoni and Chyruk (2014).

[4] Obviously, this covariance is a sufficient statistic only in a very simple model (see Section 2). But the covariance of marginal utility - and hence economic activity - and inflation is important in a broad class of asset pricing models.

1.1 Related Literature

Our paper is related to several strands of literature. First, there is a large macro-asset pricing literature that attempts to explain the level and volatility of the term premium. This work typically uses endowment economies for tractability. Marshall (1992) is an early paper in this literature. Piazzesi and Schneider (2006) and Bansal and Shaliastovich (2013) are recent studies that use the long-run risk framework. The underlying logic of how risk premia are determined is similar to our paper (and is discussed in section 2), but our contribution relative to these papers is to study the *sources* of the correlations between inflation and growth that are taken as primitives in these studies. David and Veronesi (2014) also study the changes in regimes with different correlations of inflation and asset prices.

Second, a subset of this literature consists of DSGE production models with nominal rigidities that attempt to replicate various features of asset prices. Key contributions include Rudebusch and Swanson (2008, 2012), Li and Palomino (2014), Christiano et al. (2010), Palomino (2012), and Swanson (2015). Especially close in spirit is the recent paper by Campbell, Pflueger and Viceira (2014) that emphasize structural breaks in monetary policy rules and how these affect asset prices and their correlations. Our contribution relative to all these papers is to introduce the ZLB and to focus on the recent changes since the Great Recession started. The contemporaneous study by Nakata and Tanaka (2016) is also closely related, with a fairly similar message but differences in empirical work and details of the model.

Third, our paper relates to the vast macro literature on the effects of the zero lower bound (ZLB). Seminal contributions include Krugman (1997) and Eggertsson and Woodford (2003). (2014) evaluates the pertinence of the ZLB mechanism, which remains disputed. In particular, our nonlinear method is related to the contributions of Fernandez-Villaverde et al. (2012), Ngo (2015) and Miao and Ngo (2015).

Finally, the broader question of the relation between stock prices and inflation has long a long history dating back at least to Fama and Schwert (1977) who showed that stocks appeared to be affected negatively by inflation, a result widely viewed as “puzzling” since stocks are claims to real assets. Modigliani and Cohn (1979) argued that investors suffered from money illusion. Boudoukh and Richardson (1993) and Campbell and Vuolteenaho (2004) revisited this issue. On the empirical side, Bernanke and Kuttner (2005) and Rigobon and Sack (2014) demonstrate that monetary policy surprises have a large effect on stock prices. Duarte (2013) also emphasizes the change in correlation and studies how inflation affects the cross-section of stock returns . Fleckenstein et al. (2014, 2015) study the pricing of TIPS and deflation while Ang, Bekaert and Wei (2008) and Hordahl and Tristani (2010) provide estimates of inflation premia. Gorodnichenko and Weber (2016) and Weber (2016) study the heterogeneity in price flexibility and demonstrate that it affects the responses of stocks to monetary policy shocks. Gali (2014) links monetary policy to asset pricing bubbles.

2 Why would the inflation risk premium be higher at the ZLB?

In order to provide some basic intuition, it is convenient to use a stripped-down, representative agent, endowment economy model. Suppose that the representative consumer has expected utility with constant relative risk aversion:

$$E\sum_{t=0}^{\infty}\beta^t\frac{C_t^{1-\gamma}}{1-\gamma},$$

and that consumption growth and inflation are conditionally jointly log-normally distributed. Specifically, denote log consumption growth by $\Delta c_{t+1} = \Delta\log C_{t+1}$ and log inflation by $\pi_{t+1} = \Delta\log P_{t+1}$ (where P_t is the CPI) and assume that

$$\begin{pmatrix} \Delta c_{t+1} \\ \pi_{t+1} \end{pmatrix} \sim N\left(\begin{pmatrix} \mu_{c,t} \\ \mu_{p,t} \end{pmatrix}, \begin{pmatrix} \sigma_{c,t}^2 & \rho_{c,p,t} \\ \rho_{c,p,t} & \sigma_{p,t}^2 \end{pmatrix}\right),$$

Note that the conditional means, variances and covariances $\mu_{c,t}, \mu_{p,t}, \sigma_{p,t}, \sigma_{c,t}, \rho_{c,p,t}$ can vary arbitrarily over time.

The critical parameter is $\rho_{c,p,t}$, which may be positive or negative, and measures the exposure of inflation to consumption growth risk:

$$\rho_{c,p,t} = Cov_t\left(\Delta c_{t+1}, \pi_{t+1}\right).$$

Intuitively, a positive $\sigma_{p,t}$ corresponds to the case where "demand shocks" dominate: low consumption is associated with low inflation, while a negative $\sigma_{p,t}$ corresponds to the case where "supply shocks" dominate: low consumption is associated with high inflation. This covariance determines the inflation risk premium, as we now show.

For simplicity, we will focus on one-period bonds. (One may think of the time period as being 10 years.) The real log stochastic discount factor is

$$\log M_{t+1} = \log\beta - \gamma\Delta c_{t+1},$$

and the nominal log stochastic discount factor is

$$\log M_{t+1}^{\$} = \log M_{t+1} - \pi_{t+1}.$$

Simple calculations show that the log real risk-free rate is

$$\begin{aligned} \log R_{t+1}^{f} &= -\log E_t\left(M_{t+1}\right), \\ &= -\log\beta + \gamma E_t\left(\Delta c_{t+1}\right) - \frac{\gamma^2}{2}Var_t\left(\Delta c_{t+1}\right). \end{aligned}$$

the familiar formula that decomposes the riskless rate into impatience, intertemporal substitution, and precautionary savings.

The log nominal risk-free rate is

$$\begin{aligned} \log R_{t+1}^{f,\$} &= -\log E_t\left(M_{t+1}^{\$}\right), \\ &= \log R_{t+1}^{f} + E_t\left(\pi_{t+1}\right) - \frac{1}{2}Var_t\left(\pi_{t+1}\right) - \gamma Cov_t\left(\pi_{t+1}, \Delta c_{t+1}\right). \end{aligned}$$

The breakeven rate is the difference in the yields of these two bonds, or in logs:

$$\begin{aligned} BE_t &= \log R_{t+1}^{\$} - \log R_{t+1} \\ &= E_t\left(\pi_{t+1}\right) - \frac{1}{2}Var_t\left(\pi_{t+1}\right) - \gamma Cov_t\left(\pi_{t+1}, \Delta c_{t+1}\right). \end{aligned}$$

This shows that the (log) breakeven rate is the sum of expected (log) inflation, a Jensen adjustment,[5] and a risk premium term which equals risk aversion γ multiplied by the covariance of consumption growth and inflation $\rho_{c,p,t}$. If investors are risk-neutral ($\gamma = 0$), and neglecting the Jensen term, the breakeven measures perfectly expected (log) inflation. However, most macroeconomic models that replicate asset prices require high risk aversion, suggesting that the inflation risk premium component may be large.

Intuitively, if the covariance $\rho_{c,p,t} < 0$, supply shocks dominate, and breakevens overestimate inflation. Nominal bonds are risky assets, since their real payoff is low in states of the world where inflation is high, which on average coincide with low consumption growth and high marginal utility. Hence, agents require a premium to hold nominal bonds, so the nominal yield is higher than it would be under risk-neutrality. On the other hand, if $\rho_{c,p,t} > 0$, demand shocks dominate, inflation is a hedge, and breakevens underestimate inflation.

The covariance however does not depend solely on which kind of shocks are expected to dominate, but also on the propagation mechanisms at work. If the ZLB binds, demand shocks may be amplified, while supply shocks could have weak or even opposite effects on output than usual. This would affect the covariance even if the variances of the underlying fundamental shocks remain constant. To see this in more detail, suppose there are two fundamental shocks, ε_d and ε_s. Inflation goes up with "demand" shock, but down with "supply" shock. To a linear approximation, we can write

$$\Delta c_{t+1} = \lambda_{c,d}\varepsilon_{d,t+1} + \lambda_{c,s}\varepsilon_{s,t+1},$$

$$\pi_{t+1} = \lambda_{\pi,d}\varepsilon_{d,t+1} + \lambda_{\pi,s}\varepsilon_{s,t+1},$$

and as a result

$$Cov_t(\Delta c_{t+1}, \pi_{t+1}) = \underbrace{\lambda_{c,d}\lambda_{\pi,d}}_{>0}\sigma_d^2 + \underbrace{\lambda_{c,s}\lambda_{\pi,s}}_{<0}\sigma_s^2$$

where $\lambda_{c,d} > 0, \lambda_{\pi,d} > 0$, $\lambda_{c,s} > 0$ and $\lambda_{\pi,s} < 0$ typically. At ZLB, both $\lambda_{c,d}$ and $\lambda_{\pi,d}$ increase, leading the covariance to increase and the inflation risk premium to fall. Moreover, $\lambda_{c,s}$ falls and may even become negative, as the economy benefits less from positive supply shocks, while $\lambda_{\pi,s}$ tends to become more negative. These forces conjure to make the covariance become more negative. We next turn to the data to see which case is more realistic - and we will argue that since 2009, the major movements in breakevens have been positively correlated with the stock market, which suggests that $\rho_{c,p,t} > 0$.[6]

3 Changes in the relation between stock prices and inflation

This section presents reduced-form evidence that asset markets now view inflation as a net positive for the economy. We first document changes in the correlation of inflation compensation (inflation breakevens or inflation swaps) with stock prices; we then review the response of asset prices to news about inflation and to actual inflation; and finally we construct from the cross-section of US stocks a portfolio that "mimics" news about inflation and document its behavior since 2005.

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[5] The source of this term is that the real payoff of a nominal bond depends inversely on inflation. Consequently, higher uncertainty about inflation leads to higher expected payoffs. This term is typically small.

[6] Our approach is to use stock returns as a measure of news about the economy rather than consumption, which is notoriously difficult to measure. The small sample makes it attractive to rely on asset price measures.

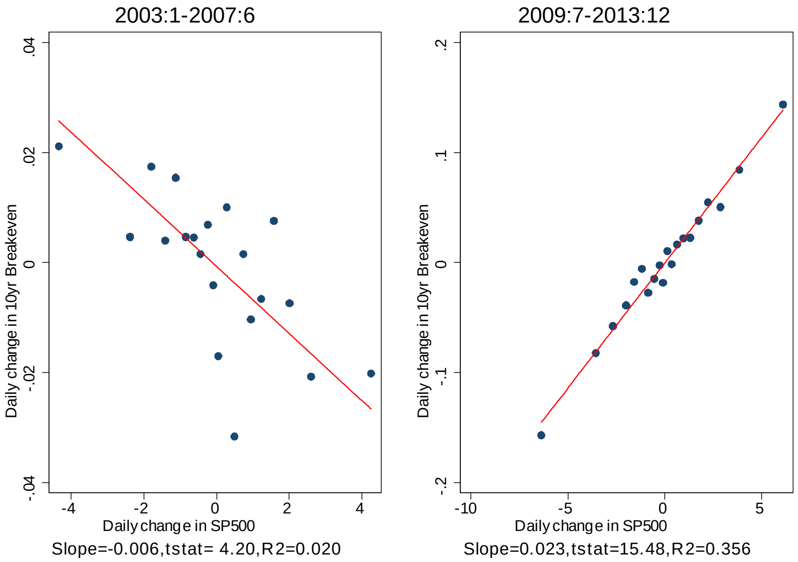

Figure 2: Scatter plot of daily changes in SP500 (x-axis) vs. daily changes in 10 year breakevens (y-axis) for two subsamples: before and after 2008, with regression lines superimposed.

3.1 Correlation of stock prices and inflation compensation

We start by illustrating how the correlation of breakeven inflations (the difference between the 10 year nominal and real (TIPS) yields) with stock prices changes after 2008. We focus on the period after mid-2009 because TIPS markets were disrupted during the peak of the financial crisis (see Fleckenstein et al. (2014)). Figure 2 plots the daily changes in SP500 vs. the daily changes in breakevens.[7] The left panel demonstrates that in the 2003-2007 sample, the correlation is essentially zero. The right panel shows that the correlation becomes very strong after 2009. A 1% increase in the SP500 is associated with a decrease of 0.6bps in the breakeven before the crisis (t-stat: 4.2), but with an increase of 2.3bps after the crisis (t-stat: 15.48). Table 1 reports these correlations for different maturities as well as correlations with nominal and real Treasury yields.

One might worry that nominal treasuries are "special" in terms of their liquidity. Inflation swaps provide an alternative measure of inflation compensation. Figure 3 shows that the results with one-day inflation swaps are very similar to those with breakevens: the slope is 1.7 instead of 2.3 post-crisis, and -0.4 instead of -0.6 pre-crisis.

Another potential concern is that the daily changes in prices reflect mostly market sentiment rather than hard news.[8] Figure 4 depicts the correlation between 20-day changes in SP500 vs. 20-day changes in 10 year breakeven. The change in the relation is still very striking between the two subsamples. The slope shifts from -0.1 to 2.5 between the two subsamples.

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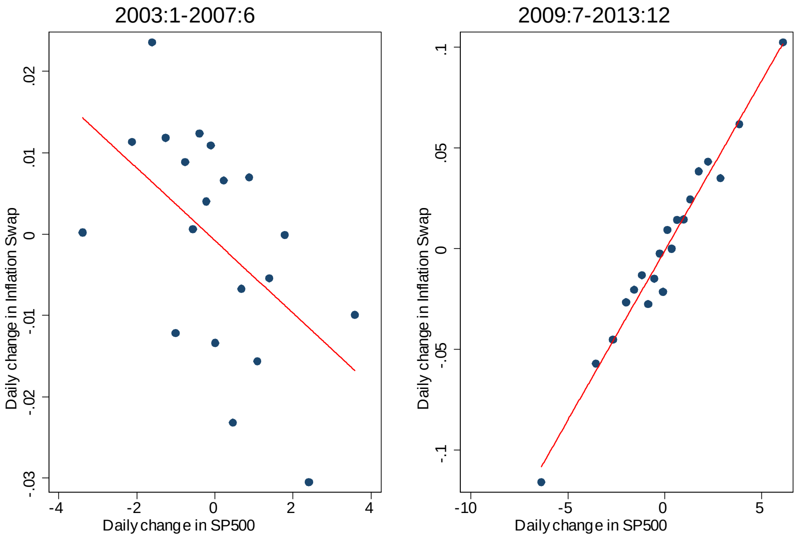
[7] We start the earliest sample in January 2003 because TIPS liquidity was limited before that date. Note also that in this and all the other scatter plots of the paper, we plot only 20 bins of the data to make the graphs easier to read. The regression statistics refer to the full sample.

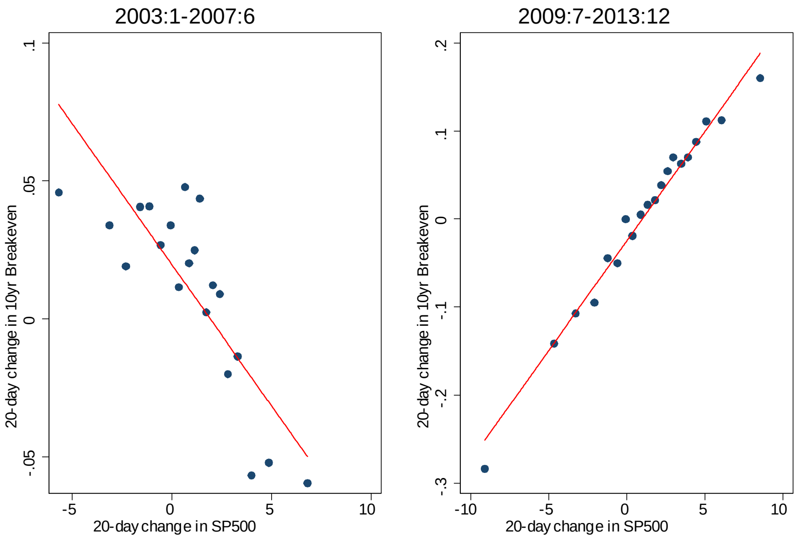
[8] Indeed, there is evidence that the long-run response of the market to macro news is stronger than the short-run response; see XXX.



Slope=-0.004,tstat= 2.27,R2=0.011

Slope=0.017,tstat=13.72,R2=0.248

Figure 3: Scatter plot of daily changes in SP500 (x-axis) vs. daily changes in 10 year inflation swap (y-axis) for two subsamples: before and after 2008, with regression lines superimposed.



Slope=-0.010,tstat= 7.84,R2=0.057

Slope=0.025,tstat=21.65,R2=0.390

Figure 4: Scatter plot of 20-day changes in SP500 (x-axis) vs. 20-day changes in 10 year breakevens (y-axis) for two subsamples: before and after 2008, with regression lines superimposed.

	SP500	G10	G5	GF5	TIPS10	TIPS5	TIPSF5	BE 10	BE 5	BE F5
	Panel A: Jan 2003 through May 2007									
SP500	1.00	0.15	0.15	0.13	0.14	0.13	0.13	**0.05**	**0.06**	**0.02**
G10	0.15	1.00	0.96	0.95	0.85	0.79	0.75	0.50	0.40	0.38
G5	0.15	0.96	1.00	0.83	0.84	0.81	0.70	0.45	0.44	0.27
GF5	0.13	0.95	0.83	1.00	0.79	0.70	0.74	0.51	0.33	0.46
TIPS10	0.14	0.85	0.84	0.79	1.00	0.92	0.90	-0.03	0.00	-0.04
TIPS5	0.13	0.79	0.81	0.70	0.92	1.00	0.64	-0.00	-0.16	0.15
TIPSF5	0.13	0.75	0.70	0.74	0.90	0.64	1.00	-0.05	0.19	-0.25
Breakeven 10	0.05	0.50	0.45	0.51	-0.03	-0.00	-0.05	1.00	0.77	0.80
Breakeven 5	0.06	0.40	0.44	0.33	0.00	-0.16	0.19	0.77	1.00	0.22
Breakeven F5	0.02	0.38	0.27	0.46	-0.04	0.15	-0.25	0.80	0.22	1.00
	Panel B: June 2009 through Nov 2012									
SP500	1.00	0.53	0.43	0.55	0.29	0.13	0.34	**0.46**	**0.40**	**0.37**
G10	0.53	1.00	0.92	0.95	0.77	0.58	0.72	0.61	0.52	0.50
G5	0.43	0.92	1.00	0.76	0.73	0.67	0.60	0.53	0.52	0.37
GF5	0.55	0.95	0.76	1.00	0.71	0.45	0.74	0.61	0.46	0.54
TIPS10	0.29	0.77	0.73	0.71	1.00	0.82	0.88	-0.04	0.00	-0.07
TIPS5	0.13	0.58	0.67	0.45	0.82	1.00	0.46	-0.11	-0.29	0.08
TIPSF5	0.34	0.72	0.60	0.74	0.88	0.46	1.00	0.03	0.24	-0.17
Breakeven 10	0.46	0.61	0.53	0.61	-0.04	-0.11	0.03	1.00	0.81	0.85
Breakeven 5	0.40	0.52	0.52	0.46	0.00	-0.29	0.24	0.81	1.00	0.38
Breakeven F5	0.37	0.50	0.37	0.54	-0.07	0.08	-0.17	0.85	0.38	1.00

Table 1: Correlation of the daily changes in the SP500, and in the changes in the of yields: 10 year, 5 year, and 5 year forward Treasuries, TIPS, and breakevens.

3.2 Response to inflation releases

One concern is that inflation compensation might be reflecting other factors than expected inflation. This leads us to a second piece of evidence to study more directly the response of stock prices to inflation. We follow the event study approach and regress the daily return on the SP500 on the "surprise" on days of macro announcements, i.e. the difference between the data as released by the statistical agency and the median forecast made by economists (and collected by Action Economics /MMS). Below is the empirical model:

$$R_t = \alpha + \beta Surprise_t + \varepsilon_t,$$

where R_t is the daily return on the SP500, and *Surprise* is the difference between the data as released by the statistical agency and the median forecast made by economists.

We are now in the right position to examine if there is any structural break in the relationship between asset prices and inflation. We first implement the Quandt Likelihood Ratio (QLR) test to test for an unknown structural break in the coefficient β. We use the surprise to core CPI as a regressor. Figure 5 shows the F-statisic that is computed for all potential break dates in the central 70% of the sample. The critical value at 1% level of significance is 12.16, from Andrew (2003). We find only one break date at 1% level of significance, which is January 2008, with the QLR statistic of 12.3. In addition, we use the Chow test to test for a known break date of December 2008 - when the federal funds rate hit the ZLB. Interestingly, we are not able to reject December 2008 as the break date either.

Based on our structural break finding, we report regression results for two sub-samples, before 2008 and after 2008 (or before and after 2009, the results are very similar). Table 2 focuses on the CPI and PPI releases and adds the employment report (nonfarm payroll) for comparison. Interesting, column 1 shows that before 2009, the stock market had a significant *negative* response to both CPI and PPI (core) releases. Column 2 shows that the stock market has a weak and insignificant response to CPI core surprises, and a positive and significant response to PPI surprises, after 2009. In terms of magnitude, if CPI core inflation was one 'tick' (1/10th of a percent) higher than expected, stock prices on average fell 0.2% on that day before the crisis, but only an insignificant 0.04% after the crisis.

One simple way to understand this switch - and which is consistent with our ZLB argument - is that before 2009, an unexpected decrease in inflation led to the presumption that the Fed would cut rates, helping stocks. After 2009, the Fed is unable to respond. Note also that the responses of inflation breakeven or inflation swaps remain relatively unchanged suggests that the releases have a roughly similar informational content for inflation before and after 2009. The change in the response of stock prices to the employment report is, on the other hand, consistent with Boyd, Hu and Jagannathan (2005).

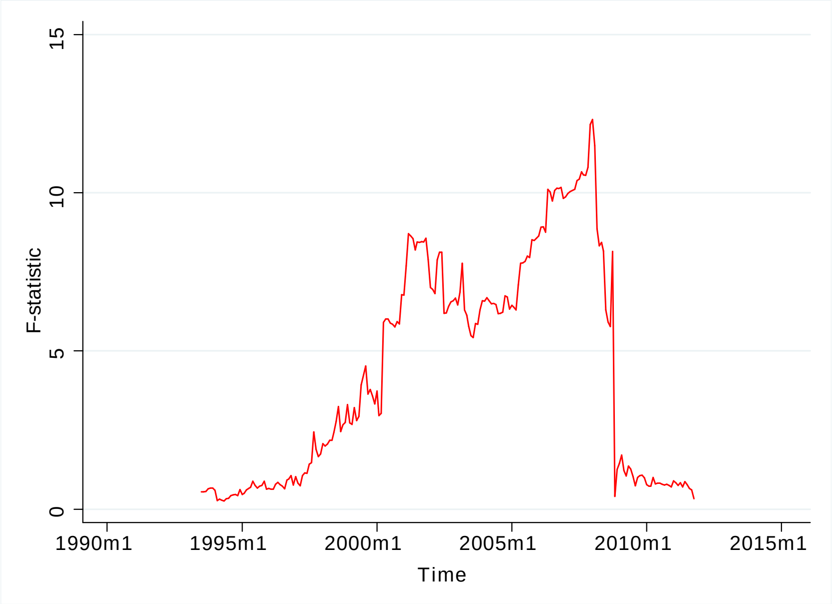


Figure 5: The F-statistic is computed for all potential break dates in the central 70% of the sample. The depend variable is the return on the SP500, the regressor is the surprise to core CPI. The sample is from August 1989 - December 2015. The critical value is 12.16 at 1% level of significance, given in Andrew (2003). The only break date is January 2008 with the QLR statistic of 12.3.

	SP500		5y Treasury		5y Inflation Swap		5 y Inflation Breakeven	
Employment	-0.002**	0.005**	0.053***	0.080***	0.021	0.031***	0.020***	0.027***
	(0.001)	(0.002)	(0.006)	(0.014)	(0.024)	(0.012)	(0.007)	(0.008)
CPIcore	**-2.218****	**-0.435**	22.489***	-8.644	31.000**	20.763***	18.144***	18.178***
	(0.949)	(1.087)	(3.894)	(9.317)	(12.052)	(6.515)	(5.333)	(6.559)
PPIcore	**-0.628****	**1.209****	2.565	5.883**	3.920*	10.766***	2.212	8.484***
	(0.291)	(0.538)	(1.581)	(2.614)	(2.134)	(2.805)	(2.226)	(2.381)
Observations	11,697	1,704	11,697	1,704	1,042	1,703	1,731	1,703
R-squared	0.002	0.006	0.017	0.042	0.016	0.023	0.013	0.023
Before 2009	y	n	y	n	y	n	y	n
Since 2009	n	y	n	y	n	y	n	y

Robust (White) standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 2: Response of asset prices to surprise in macro announcements. Daily regression in samples before and after 2009.

	1925-1939	1940-1959	1960-1984	1985-2002	1960-2007	2003-2007	2008-2015
β	1.534	-0.309	-1.625**	-1.716	-1.704***	-1.956***	1.510
	(1.065)	(0.376)	(0.700)	(1.527)	(0.546)	(0.722)	(1.388)
Obs	168	240	300	216	576	60	96
R2	0.013	0.003	0.021	0.007	0.019	0.098	0.020
White SE; *** p<0.01, ** p<0.05, * p<0.1							

Table 3: Response of the CRSP value-weighted return to inflation, for different subsamples. Monthly data.

3.3 Response to inflation

More directly, we can estimate the response of (nominal) stock returns to inflation, in the spirit of Fama and Schwert:

$$R_t = \alpha + \beta \pi_t + \varepsilon_t,$$

where π_t is CPI inflation, R_t is the CRSP total return.[9] Table 3 confirms the results of Fama and Schwert, that is higher inflation is associated with lower nominal stock returns (rather than higher as one might expect under the Fisher hypothesis). This result varies significantly across periods, however. It holds in the 1960-2007 period, but not since 2008. Interestingly, the only other period where the coefficient was positive is the Great Depression - when short-term money market rates were also very low.

One might worry that this relation is driven by low frequency changes in inflation that are anticipated as opposed to unexpected "news" or "surprises" to inflation. We propose two ways of decomposing inflation into expected vs. unexpected components. First, following Fama and Schwert, we use the T-bill rate as a proxy for expected inflation - a good assumption if the real rate is fairly constant. Hence, we estimate

$$R_t = \alpha + \beta \left(\pi_t - Tbill_t\right) + \gamma Tbill_t + \varepsilon_t.$$

As a second method, we use as proxy for expected inflation the current inflation (year-over-year to smooth out the noise). This leads us to estimate

$$R_t = \alpha + \beta \left(\pi_t - \pi_t^E\right) + \gamma \pi_t^E + \varepsilon_t.$$

Last, we also report the results using core inflation rather than total inflation. All these results (Tables 4-6) point to a significant change in behavior post 2008.

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[9] We use CRSP to extend the sample and include the Great Depression. Results are nearly identical if one uses SP500 where available.

	1925-1939	1940-1959	1960-1984	1985-2002	1960-2007	2003-2007	2008-2015
β	**1.533**	**-0.344**	**-1.681****	**-2.405**	**-1.949*****	**-1.956*****	**2.186***
	(1.073)	(0.388)	(0.822)	(1.572)	(0.589)	(0.733)	(1.228)
γ	1.489	-2.197	-1.539*	1.497	-1.197	-3.274	-32.845***
	(5.094)	(3.821)	(0.919)	(2.500)	(0.796)	(2.727)	(9.165)
Obs	168	240	300	216	576	60	96
R2	0.013	0.004	0.021	0.020	0.020	0.104	0.131
White SE; *** p<0.01, ** p<0.05, * p<0.1							

Table 4: Response of the CRSP value-weighted return to inflation minus expected inflation (proxied by the Tbill rate) and expected inflation, for different subsamples. Monthly data.

	1985-2002	1960-2007	2003-2007	2008-2015
β	**-2.608**	**-3.207*****	**-2.377****	**2.087**
	(1.801)	(0.717)	(1.171)	(1.558)
γ	-2.466	-3.003***	-2.819**	1.156
	(1.714)	(0.676)	(1.241)	(1.519)
Obs	216	576	60	96
R2	0.010	0.030	0.107	0.127
White SE; *** p<0.01, ** p<0.05, * p<0.1				

Table 5: Response of the CRSP value-weighted return to inflation minus expected inflation (proxied by last month's year-over-year inflation) and expected inflation, for different subsamples. Monthly data.

	1985-2002	1960-2007	2003-2007	2008-2015
β	**-5.486**	**-2.659*****	**-6.675**	**2.966**
	(3.643)	(0.947)	(4.168)	(7.721)
γ	-4.763	-2.439***	-7.182*	0.723
	(3.430)	(0.900)	(4.199)	(7.251)
Obs	216	576	60	96
R2	0.017	0.013	0.067	0.042
White SE; *** p<0.01, ** p<0.05, * p<0.1				

Table 6: Response of the CRSP value-weighted return to core inflation minus expected core inflation (proxied by last month's year-over-year core inflation) and expected core inflation, for different subsamples. Monthly data.

3.4 An inflation-mimicking portfolio

Another place where we may find useful information about inflation is the cross-section of stocks. Some firms are naturally more sensitive to inflation, due to the nature of their assets, their business, their liabilities (debts, rents, pensions, etc.). We can create a long-short portfolio of stocks based on their inflation sensitivity. This allows tracking an asset that is a "inflation hedge" over a long period of time (the sample is longer than with TIPS or inflation swaps), using high-frequency data, and without the liquidity problems that TIPS or inflation swaps may have.

We implement this as follows. On the last day of each year, we sort the 500 stocks with largest market capitalization in CRSP by inflation sensitivity. The inflation sensitivity is estimated using the response of the stock to CPI announcements over the previous 3 years of data. Specifically, we run for each stock:

$$R_{it} = \alpha_i + \beta_i NewsCPI_t + \varepsilon_{it},$$

over the 36 (3 years times 12 months) days of CPI releases; here $NewsCPI_t$ is the difference between actual CPI inflation and the forecast made by economists before the release.[10] As may be expected, we find that technology firms have typically low (or negative) β_i while commodity or energy firms and banks have positive β_i. (A list of the top and bottom 50 stocks by inflation sensitivity in 2011 is included in appendix.)

We then create an (equally-weighted) portfolio long the top quartile of inflation sensitivity and short the bottom quartile. This portfolio is effectively a "breakeven in the stock market". We first document that this portfolio behaves similarly to actual breakevens. Figure 6 depicts the correlation of this portfolio with the SP500 before and after the crisis. We see that before the crisis, the correlation is strongly negative, but it becomes strongly positive after the crisis. This is similar to the results obtained with breakevens or inflation swaps. An alternative illustration of the same fact involves reporting the market beta of the inflation portfolio. This beta shoots up starting in 2008, see figure 7.

Finally, figure 8 shows the cumulated return on this long-short portfolio together with year-over-year total CPI and core inflation. The returns are high during the financial crisis - the strategy generates around +70% from 2007 through 2011 - then are low (-30% from 2011 through 2015). The returns broadly follow realized year-over-year inflation. In particular, it is perhaps not surprising that this strategy has a low return post 2011 - inflation was lower than expected during that period. The period of the financial crisis is more surprising since inflation fell while this portfolio did well. Perhaps the increase in value of the portfolio reflected a fear of inflation which never materialized. Alternatively, there may have been a repricing of risk whereby high inflation beta stocks, that were perceived as risky initially, became more attractive leading to a large increase in value.

3.5 Correlation of inflation and economic activity

Of course, a more direct test of the model is that there should be a direct change in the correlation of inflation and economic activity. It is difficult to test this proposition directly because of the short sample

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[10] We use core inflation. We obtained fairly similar results using total inflation, as well as PPI or core PPI inflation.

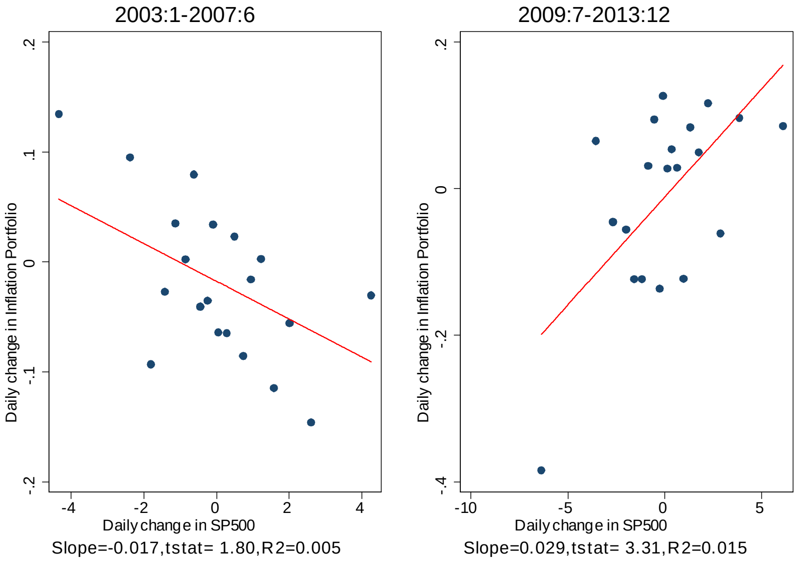

Figure 6: Scatter plot of daily changes in SP500 (x-axis) vs. daily changes in the inflation-mimicking portfolio (y-axis) for two subsamples: before and after 2008, with regression lines superimposed.

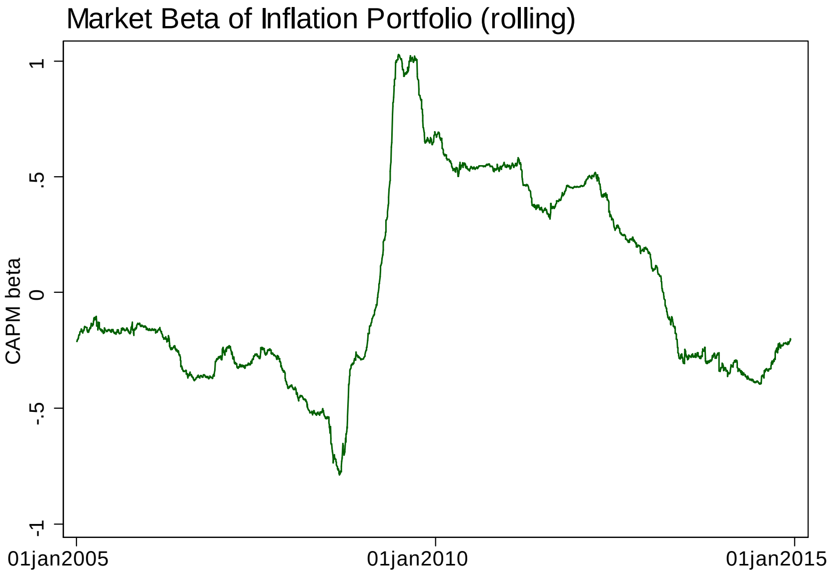

Figure 7: Rolling window (120 days) CAPM beta of the inflation-mimicking portfolio.

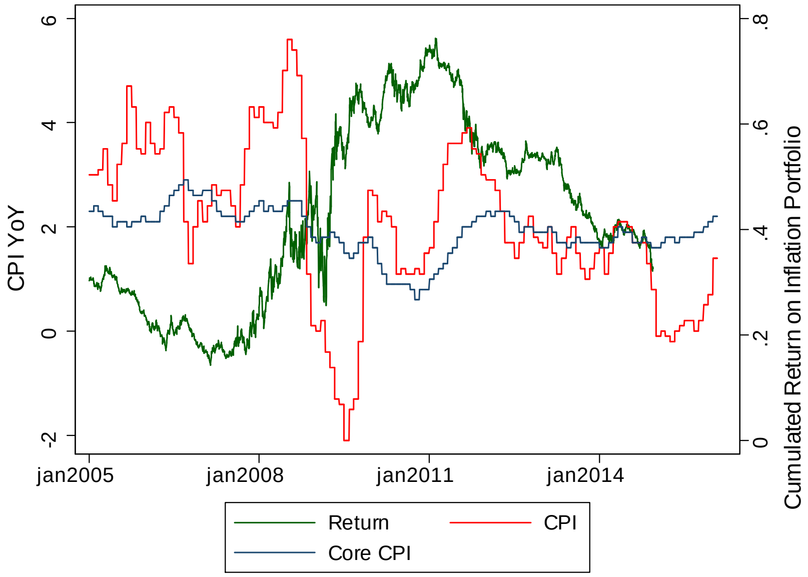

Figure 8: Cumulated return on the inflation-mimicking portfolio (long the top 25% inflation sensitivity stocks and short the bottom 25% inflation sensitivity stocks), together with year-over-year CPI and core CPI inflation.

and noisy measures of economic data.[11] Nevertheless, in this section we present some simple evidence. We first show the correlation of inflation and real consumption growth of nondurables and services, both measured as a three-month change in figure 9. There is an important change in this correlation between the two samples. However this result is driven by a few observations, especially 2008Q4. Moreover, this result does not hold if one focuses on core CPI inflation rather than total CPI inflation.

One might also want to focus on innovations instead. Figure 10 shows the correlation of innovations of consumption and core CPI inflation, where innovations are calculated as the residuals from a regression on 3 lags of both variables.

Finally, we can also look at broader measures of economic activity - for instance, the monthly GDP series constructed by the private firm Macroeconomic Advisers. The results are broadly similar.

Table XXX (to be added) reports the correlation of various economic indicators with inflation in different subsamples.

4 Model

Our model follows closely Rudebusch and Swanson (2012, thereafter RS). The main difference is that we explicitly take into account the zero lower bound.[12] These authors themselves build closely on the standard New Keynesian model as outlined for instance in Gali (2012) and Woodford (2003). The main

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[11] Moreover, while we focus on direct demand shocks in our analysis, it is also possible that the shocks driving asset prices are changes in expectations (e.g., positive news about the future, or a lower perceived risk of "disaster"). These would have broadly similar effects but might not be detectable in economic data if the news are not actually realized.

[12] We also use Rotemberg rather than Calvo pricing, chiefly to economize on state variables, and use different shocks, and a different monetary policy rule.

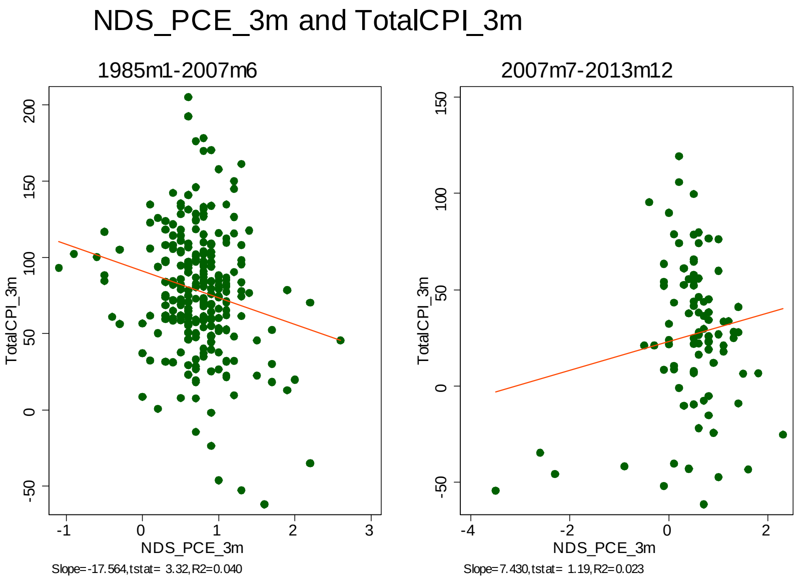

Figure 9: Three month change in CPI inflation (y-axis) and in real personal consumption expenditures on goods and services (x-axis), before and after 2008m1.

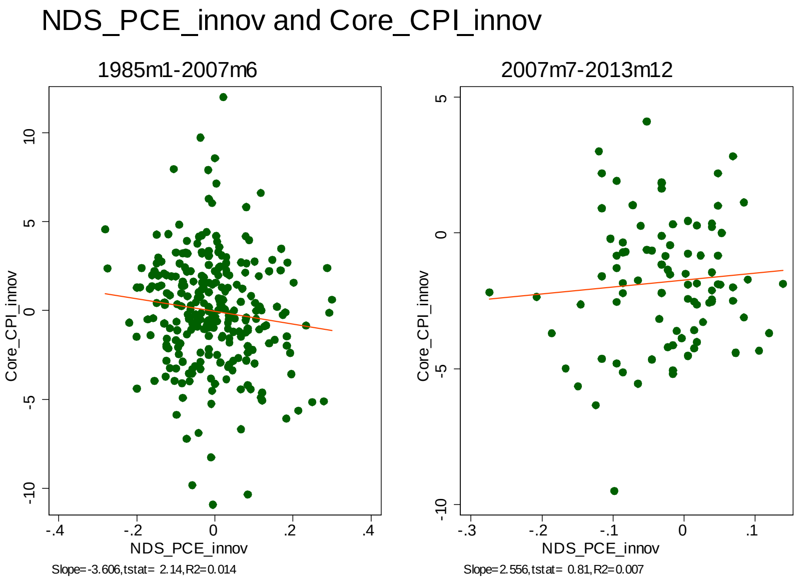

Figure 10: Innovations in monthly Core CPI inflation (y-axis) and in real personal consumption expenditures on goods and services (x-axis), before and after 2008m1. Innovations calculated by a regression on three lags of both variables.

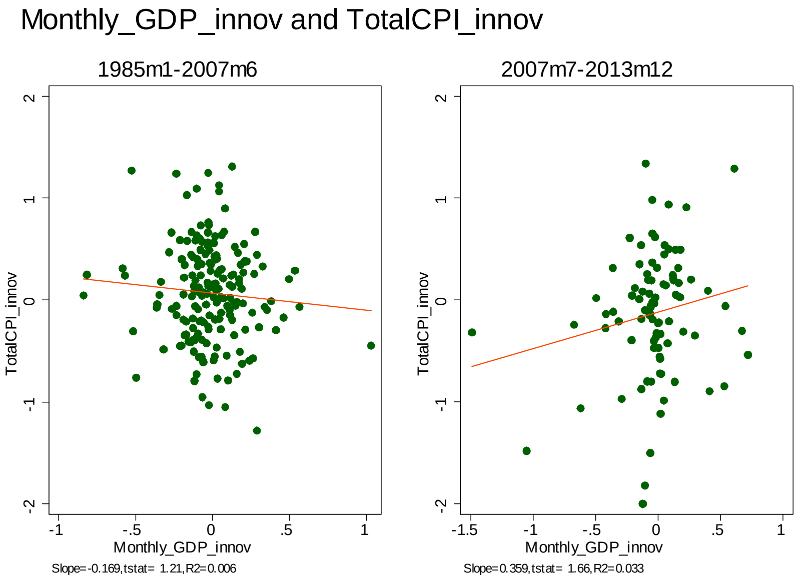

Figure 11: Innovations in monthly Core CPI inflation (y-axis) and monthly GDP (as estimated by Macroeconomic Advisers) (x-axis), before and after 2008. Innovations calculated by a regression on three lags of both variables.

difference they introduce relative to the standard model is that they incorporate recursive preferences as in Epstein and Zin (1989) as well as different shocks.

4.1 Household

We follow Rudebusch and Swanson's version of Epstein and Zin (1989):

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

As RS explain, instantaneous utility may be negative so one may need to flip signs:

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

The per period utility is assumed to be

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

where C_t is consumption, N_t is labor.

The budget constraint is

$$P_t C_t + \xi_t B_t + Q_t S_t = W_t N_t + \Pi_t + R_{t-1} B_{t-1} + (Q_t + D_t) S_{t-1},$$

where S_t is the number of shares bought, B_t the quantity of risk-free assets (government bonds or money), Q_t the stock price, D_t is dividend, Π_t profits, and W_t the wage rate. For simplicity, we assume that the shares are not claims to the firms' profits but simply a levered claim to consumption, $D_t = C_t^{\lambda}$, where λ is a parameter as in Abel (1999).

We also introduce a shock to the "cost" of risk-free asset ξ_t. This shock plays the same role in our model as the "discount factor" shock used in much of the New Keynesian literature. We interpret this shock as reflecting a time-varying preference for holdings of safe assets.[13] We will also refer to ξ_t as a "demand shock" for brevity.

The labor supply equation is simply

$$w_t = \frac{u_2 (C_t, N_t)}{u_1 (C_t, N_t)} = C_t^{\sigma} \chi N_t^{\upsilon}. \tag{1}$$

The real stochastic discount factor is

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

and the nominal stochastic discount factor is

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

where Π_{t+1} is gross inflation P_{t+1}/P_t.

The first order condition links the nominal short-term interest rate to the nominal SDF:

$$1 = E_t \left[\xi_t^{-1} Y_t^{\$,(1)} M_{t+1}^{\$} \right],$$

where $Y_t^{\$,(1)}$ is the gross nominal yield on a 1-period asset.

4.2 Production and optimal price-setting

There is a number of identical monopolistically competitive firms, each of which operates a production function that is constant return to scale in labor:

$$Y_{it} = Z_t N_{it}. \tag{2}$$

Each firm faces a downward-sloping demand curve coming from the Dixit Stiglitz aggregator with elasticity of demand ε :

$$Y_{it} = Y_t \left(\frac{P_{it}}{P_t} \right)^{-\varepsilon}, \tag{3}$$

where P_t is the price aggregator

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

We use the Rotemberg (1982) assumption of quadratic adjustment costs to changing prices.[14] Specifically, the cost of changing the price from P to P' is $\frac{\phi}{2} Y \left(\frac{P'}{P} - \overline{\Pi} \right)^2$ where ϕ captures the magnitude of the costs, Y are firm sales, and $\overline{\Pi}$ is a parameter capturing "indexation", i.e. it is costless to have an inflation of $\overline{\Pi}$.

Each period, firms set their price so as to maximize

$$E_t \sum_{k=0}^{\infty} M_{t,t+k}^{\$} \left(P_{it+k} Y_{it+k} - w_{t+k} N_{it+k} - \frac{\phi}{2} Y_{it+k} \left(\frac{P_{it+k}}{P_{it+k-1}} - \overline{\Pi} \right)^2 \right),$$

---

[13] See for instance Fischer (2015) for a similar microfoundation.

[14] Miao and Ngo (2015) illustrate that some results (such as the size of the fiscal multiplier) may be affected by the price setting assumptions at the ZLB.

subject to the demand curve (3) and the production function (2).

In equilibrium, all firms choose the same price, and given quadratic adjustment costs, they adjust their price each period. A standard derivation for the optimal price yields a nonlinear version of the forward-looking Phillips curve:

$$0 = \left(1 - \varepsilon + \varepsilon\left(\frac{w_t}{Z_t}\right) - \phi(\Pi_t - \overline{\Pi})\Pi_t\right) Y_t + \phi E_t\left(M_{t+1}(\Pi_{t+1} - \overline{\Pi})\Pi_{t+1}Y_{t+1}\right),$$

where M_{t+1} is the real stochastic discount factor.

The resource constraint reads

$$C_t = \left(1 - \frac{\phi}{2}(\Pi_t - \overline{\Pi})^2\right) Y_t, \tag{4}$$

since we need to subtract price adjustment costs from output. The definition of gross domestic product similarly takes into account that price adjustment is an intermediate input:

$$GDP_t = \left(1 - \frac{\phi}{2}(\Pi_t - \overline{\Pi})^2\right) Y_t = C_t.$$

4.3 Fundamental Shocks

We assume that:

(1) The safe asset demand shock follows an AR(1) process:

$$\log \xi_t = \left(1 - \rho_\xi\right) \log \overline{\xi} + \rho_\xi \log \xi_{t-1} + \varepsilon_{\xi,t},$$

with $\varepsilon_{\xi,t}$ i.i.d $N(0, \sigma_\xi^2)$.

(2) The level of TFP follows an AR(1) process:

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

with $\varepsilon_{z,t}$ i.i.d $N(0, \sigma_z^2)$.[15]

4.4 Monetary Policy Rule

We assume that the central bank uses the following policy rule:

$$R_t = \max\left\{1, R^* \left(\frac{\Pi_t}{\Pi^*}\right)^{\phi_\pi} \left(\frac{GDP_t}{GDP^*}\right)^{\phi_y}\right\} \tag{5}$$

where Π^* and GDP^* are the target inflation and GDP. The max operator simply reflects the truncation implied by the ZLB.

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[15] We also explored shocks to the growth rate of TFP, i.e. $\Delta \log Z_t = \rho_z \Delta \log Z_{t-1} + (1 - \rho_z)\mu_z + \varepsilon_{z,t}$.

In this case we scale up the second term of the flow utility by $Z_t^{1-\sigma}$, i.e. $u\left(C_t, N_t\right) = \frac{C_t^{1-\sigma}}{1-\sigma} - Z_t^{1-\sigma}\frac{\chi N_t^{1+\nu}}{1+\nu}$. The introduction of Z_t in the utility function is designed to ensure that employment remains stationary even with unit root technology. It may reflect home production or changing tastes as the economy grows.

4.5 Asset prices: Bonds

In order to simplify the numerical computation of the model, we study the prices of geometric consols rather than zero-coupon bonds. A nominal geometric consol with parameter λ pays 1\$ next period, then λ\$ the period after, then λ^2\$, and so on. A real consol with parameter λ has the same payoffs, but in units of final goods rather than in \$.[16]

Hence the price for a (nominal or real) consol with parameter λ satisfies the recursion:

$$q_t^{i,\lambda} = E\left[M_{t+1}^i\left(1+\lambda q_{t+1}^{i,\lambda}\right)\right] \tag{6a}$$

for $i \in \{\$, \text{real}\}$. The yield is defined as

$$Y_t^{i,\lambda} = \frac{1}{q_t^{i,\lambda}} + \lambda \tag{7}$$

where $i \in \{\$, \text{real}\}$.

We now calculate the risk-neutral price (and yield), i.e. the price (and yield) that would occur if agents were risk-neutral. The difference between the yield and the risk-neutral yield is a measure of term premium. (It coincides with the standard definition for zero-coupon bonds.)

The risk-neutral price for a (nominal or real) consol with parameter λ satisfies:

$$q_t^{i,\lambda,RN} = E_t\left[\left(1+\lambda q_{t+1}^{i,\lambda,RN}\right)\right] E_t\left[M_{t+1}^i\right], \tag{8}$$

and we can define the risk-neutral yield similar to equation 7.

The holding period returns on consols is given by the standard formula:

$$R_{t+1}^{i,\lambda} = \frac{1+\lambda q_{t+1}^{i,\lambda}}{q_t^{i,\lambda}} \tag{9}$$

where $i \in \{\$, \text{real}\}$.

We define the term premium as the difference between the log yield and the log risk-neutral yield:

$$TP_t^{i,\lambda} = y_t^{i,\lambda} - y_t^{i,\lambda,RN} \tag{10}$$

where $i \in \{\$, \text{real}\}$. Note that $TP_t^{i,0} = 0$ by construction.

We define the *inflation term premium* as the difference between the nominal term premium and the real term premium:

$$ITP_t^{\lambda} = TP_t^{\$,\lambda} - TP_t^{\text{real},\lambda}. \tag{11}$$

The slope of the yield curve is the difference between the log yield of a $\lambda-$consol and the log yield of a $0-$consol:

$$SL_t^{i,\lambda} = y_t^{i,\lambda} - y_t^{i,0} \tag{12}$$

where $i \in \{\$, \text{real}\}$.

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[16] For our simulations, we calculate these yields and prices for three values of λ. These values are chosen so that $\lambda_1 = 0$, and λ_2 and λ_3 are such that these consols have the durations of actual 5 and 10 year bonds.

4.6 Asset prices: Breakevens and Inflation premia

Inflation breakevens are the difference between the log nominal yield and the log real yield

$$BE_t^{\lambda} = y_t^{\$,\lambda} - y_t^{\lambda}. \tag{13}$$

We define expected log inflation (over the lifetime of a consol) recursively as:

$$ELI_t^{\lambda} = (1-\lambda)E_t\left(\log \Pi_{t+1}\right) + \lambda E_t(ELI_{t+1}^{\lambda}).$$

For $\lambda = 0$, this is simply the expected inflation next period, and for $\lambda \to 1$, this is the long-run average inflation in the future.

Last, the *inflation risk premium* is the difference between breakevens and expected inflation:

$$IRP_t^{\lambda} = BE_t^{\lambda} - ELI_t^{\lambda}.$$

Inflation risk premia are closely related to inflation term premia.[17]

4.7 Asset Prices: Stocks

Following Abel (1999), we define a stock as an asset with payoff $D_t = C_t^{\xi}$, where $\xi > 1$ reflects leverage. The real stock price satisfies the recursion

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

so that if we define the P/D ratio as $q_t^s = \frac{P_t^s}{D_t^s}$,we have the following recursion for the P-D ratio:

$$q_t^s = E_t\left[M_{t+1}\left(q_{t+1}^s + 1\right)\frac{D_{t+1}}{D_t}\right],$$

and the realized return on equity from t to $t+1$ is

$$R_{t+1}^e = \frac{P_{t+1}^s + D_{t+1}}{P_t^s} = \frac{q_{t+1}^s + 1}{q_t^s}\frac{D_{t+1}}{D_t}.$$

5 Quantitative Results

This section studies the quantitative implications of the model presented in the previous section. These results are preliminary - we are not yet at the stage where a “best-fitting” calibration can be presented. Rather, the goal for now is more to illustrate “comparative statics” - how some effects vary depending on whether the economy is close to the ZLB.

Due to the presence of the ZLB, we need to solve carefully the model using nonlinear methods. This is especially important because asset prices can be highly sensitive to nonlinearities. We use projection methods with cubic spline that build on the methods used in Ngo (2015) a Miao and Ngo (2015), and Fernandez-Villaverde et al. (2014).

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[17] The appendix discusses the relation between the two concepts in the more common case of zero-coupon bonds.

5.1 Parameter choices

Table 7 presents the parameters that we use together with the source of the value. Most of these parameters are standard in the New Keynesian literature. The weight on inflation in the Taylor rule is 2.[18] The level of price rigidity ϕ is set to be 238, corresponding to the Calvo probability of keeping price unchanged of 0.85. This value is somewhat higher the the value used in the New Keynesian literature without the ZLB. However, it is consistent with some empirical estimation under the ZLB, i.e. Del Negro, Giannoni, and Schorfheide (AEJ Macro 2015) where they estimate the Calvo probability of 0.87. This high value is needed to keep the response of inflation under the ZLB to be in line with the data.[19]

The persistence of technology shocks is 0.92, while the persistence of preference shock is set to be 0.9. The unconditional standard deviation of the technology shock is chosen to be 1.53%, corresponding to the standard deviation of technology innovations of 0.6%. The calibration of technology process is in line with the data during 1968-2008. The unconditional standard deviation of demand shock is set to be 0.17%, corresponding to the standard deviation of preference innovations of around 0.4%. These values are in the range of empirical estimates, see Gust, Lopez-Salido, and Smith (2012) and Aruoba and Schorfheide (2012). All of the shocks parameters help generate the simulated moments of output and labor close to what we observe in the data, see our quantitative results below for more information.

The curvature with respect to next period value in the recursive preference, α, is set to be -190, which together with the curvatures on consumption and labor in the flow/kernel utility generate the consumption relative risk aversion of about 96, see Swanson (2013) for an explanation. In our benchmark calibration, we consider conventional values of the IES of consumption, 0.5, and the Frisch elasticity of labor supply, 0.67. These values are greater than the ones used in Swanson (2013). As a result, the term premia produced by our model are only half of what we observed in the data. As explained in Swanson (2013), to raise the term premium, one wants to lower the IES of consumption and the Frish elasticity of labor supply further.

5.2 Response to shocks far from the ZLB

This section discusses the effects of technology and demand shocks when the economy is far from the ZLB.[20]

5.2.1 TFP shocks

As shown in the policy functions plotted in figure 12 or in the impulse response plotted in figure 13, an increase in productivity leads to higher consumption (and hence lower marginal utility) and higher

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[18] Although this value is slightly higher than the one commonly used in the literature without ZLB, around 1.5, it is still much smaller than the value estimated in Gust, Lopez-Salido, Smith (2012) under the ZLB. They estimate that the long-run effect of a change in inflation on interest rate is around 5.

[19] Another way to keep the response of inflation to be in line with the data under a shock that makes the ZLB bind is to raise the weight of inlation in the Taylor rule such that the long-run effect of inflation on interest rate is sufficiently high. For example, Gust, Lopez-Salido, and Smith (2012) estimate the long run effect of inflation on interest rate is 5 instead of 1.5 as in our benchmark calibration.

[20] Throughout the paper, we use “demand” and “preference” shock labels interchangeably.

Parameter	Description and source	Value
β	Subjective discount factor, RS (AEJ 2012), Woodford (2003)	0.99
α	Curvature with respect to next period value (note: CRRA=95.8)	-190.00
σ	IES is 0.5	2.00
υ	Frisch labor supply elasticity is 0.66; 0.66 and 0.28 in RS (AEJ 2012)	1.50
χ	Calibrated to achieve the steady state labor of 1/3	40.66
ε	Gross markup is 1.15, e.g. Fernandez-Villaverde et al (JEDC 2015)	7.66
ϕ_π	Weight on inflation in the Taylor rule	2.00
ϕ_y	Weight on output in the Taylor rule	0.13
ϕ	Adjustment cost, corresponding to the Calvo parameter of 0.85	238.11
ρ_z	Persistence of technology shock, 0.95 in SR12	0.92
ρ_ξ	Persistence of demand shock, 0.9 in Gust et al (2015)	0.90
σ_z	Std. dev. of the technology innovations (%)	0.60
σ_ξ	Std. dev. of the preference innovations (%)	0.17

Table 7: Parameter values used and sources.

stock prices. The latter reflects that stock price equals a present discounted value of dividends, which are proportional to consumption and hence increase with the productivity shock. Higher productivity also leads to lower inflation - as is typical with the New Keynesian model, since rigid prices prevent a full expansion of output. As a result, the covariance of consumption growth and inflation is negative, generating a positive inflation risk premium.

The effect of productivity on long-term interest rates depends both on the monetary policy rule and, mostly, on the process for productivity. Given that the later is mean-reverting, interest rates tend to go up when the level of productivity is low, since agents rationally expect higher real consumption growth in the future. This explains why in figure 14 the real rate falls with productivity. The breakeven rate reflects inflation expectations which are lower when productivity is high, since productivity is persistent. The nominal yield reflects both the real yield and inflation expectations, and hence is more strongly downward-sloping than the real yield. Overall, the real return on holding long-term bonds (nominal or real) is high if productivity goes up, given that yields fall with such a shock. Hence, long-term bonds are risky and require a positive risk premium, creating an upward-sloping yield curve.[21]

5.2.2 Demand shocks

As shown for policy functions in the figure 15 and for the impulse response in figure 16, the demand shock leads to decreases in consumption and inflation. This implies that in the model with only demand shocks, the inflation term premium would be negative because inflation is low when consumption is low. So,

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[21] When the technology shock is a random walk, the real yield curve is approximately flat since expected growth is approximately constant (not exactly, owing to the effects of monetary policy on real growth). Swanson (2015) proposes a model that fits the yield curve with random walk shocks by considering a slightly different Taylor rule.

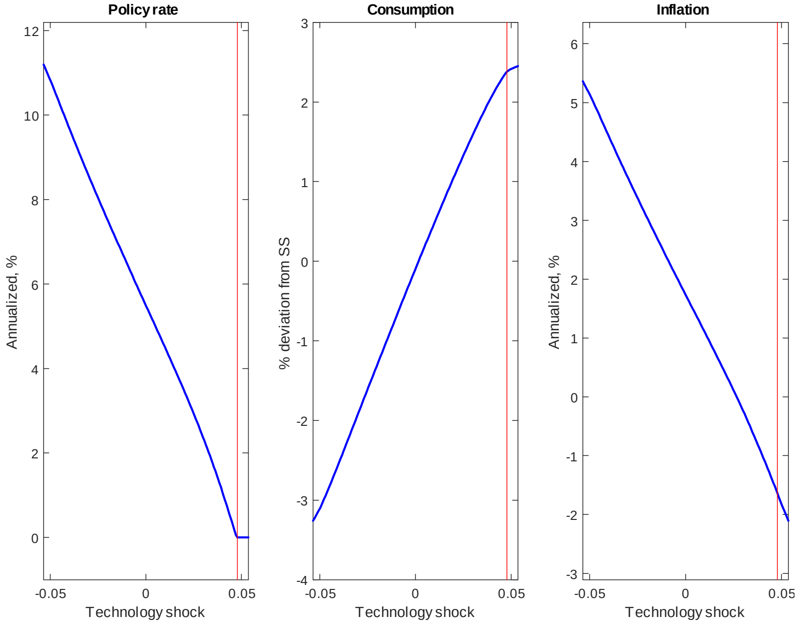

Figure 12: Policy functions - TFP shock.

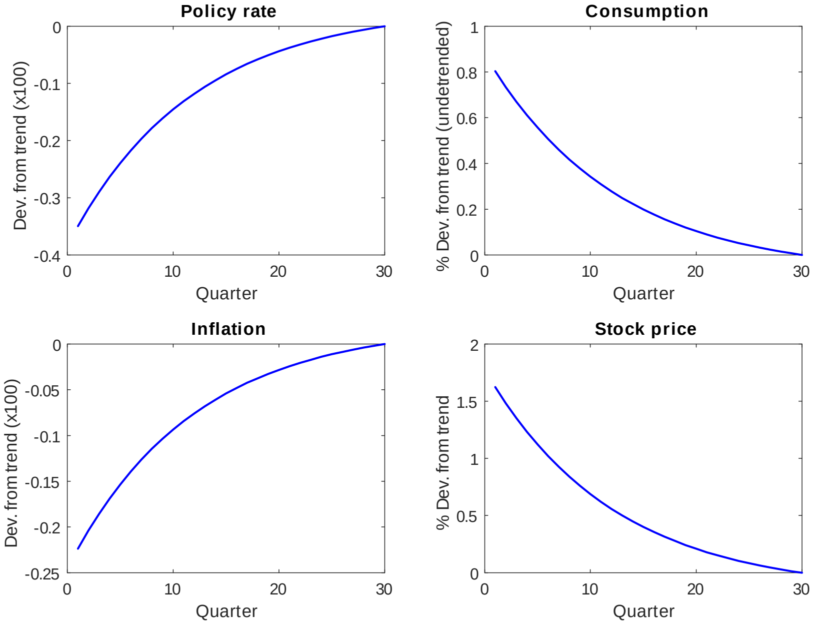

Figure 13: Impulse reponse to 1 standard deviation productivity shock, far from the ZLB.

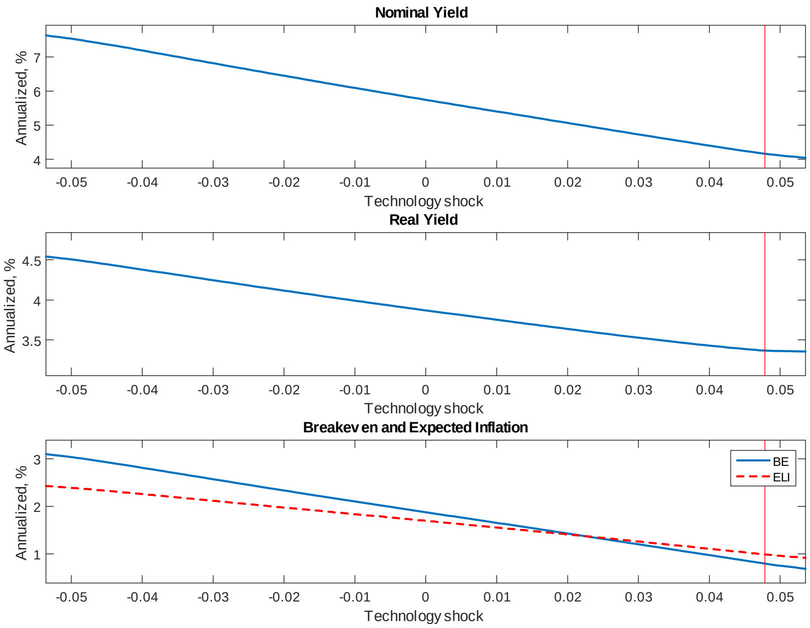

Figure 14: Policy function of long-term nominal and real yield and long-term breakeven and expected inflation, as a function of the TFP shock.

inflation is a good hedge. However, given that the TFP shock dominates the demand shock in normal times, when the economy operates far from the ZLB, bond premia reflect the effect of productivity shocks. Therefore, the inflation term premium is actually positive.

5.3 Response to shocks at the Zero Lower Bound

We again discuss separately the effect of demand and productivity shocks, but now focus on the case when the ZLB binds.

5.3.1 Demand shocks

Once the ZLB binds, the response to shocks changes significantly. As shown in the policy function figure 15, once the ZLB binds, negative demand shocks lead to a significant decline of output and inflation, since monetary policy is unable to respond.[22] To illustrate the difference of response to a preference shock when the ZLB binds vs. not, we calculate an impulse response function (IRF) when the economy is at the ZLB and compare it to the steady-state IRF (i.e., the one shown in the previous section).[23]

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[22] Implicitely, we assume that fiscal policy is not used to offset this shock. Moreover, we abstract from so-called "unconventional" policies such as forward guidance or LSAP. We plan to explore these in the future. Note, however, that it is usually believed that unconventional policies are less efficient, more uncertain, and politically more risky, leading central banks to be more reluctant to pursue them (see Evans et al. (2015) for a discussion).

[23] The details of the calculations are as follows. We calculate the difference between two paths: (i) a path with a large shock to demand that brings the economy at the ZLB, and (ii) a path with the same shock, plus 1%. The difference gives us the effect of a 1% shock at the ZLB. We replicate the same calculation but instead of having a shock to demand that makes the ZLB bind, we just have a zero shock. The figure below plots these two differences (and obviously, the second one is the standard IRF discussed in the previous section). Note that we refer to IRF but do not employ the strict definition as the effect of a shock on the conditional expectation of a future variable, $E_t y_{t+k} - E_{t-1} y_{t+k}$. Rather, these are example

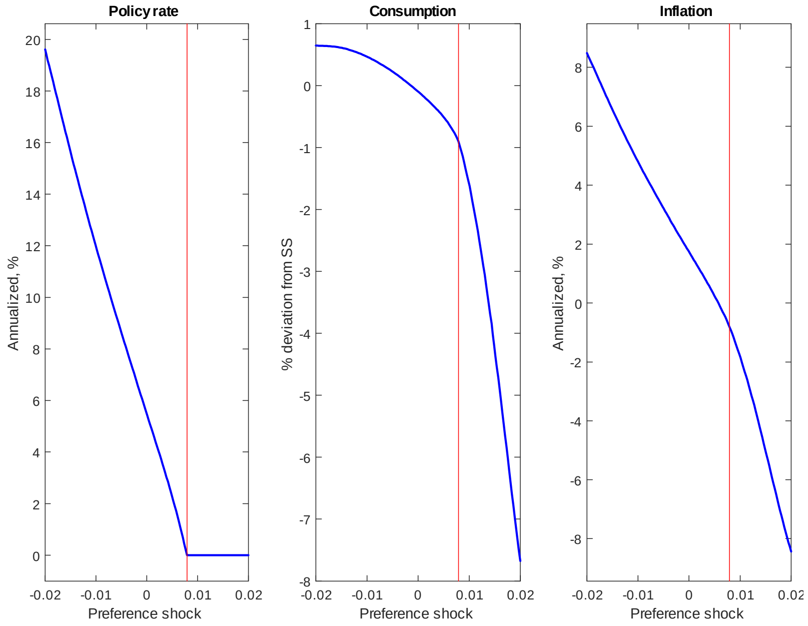

Figure 15: Policy function for the interest rate, consumption and inflation as a function of the preference shock.

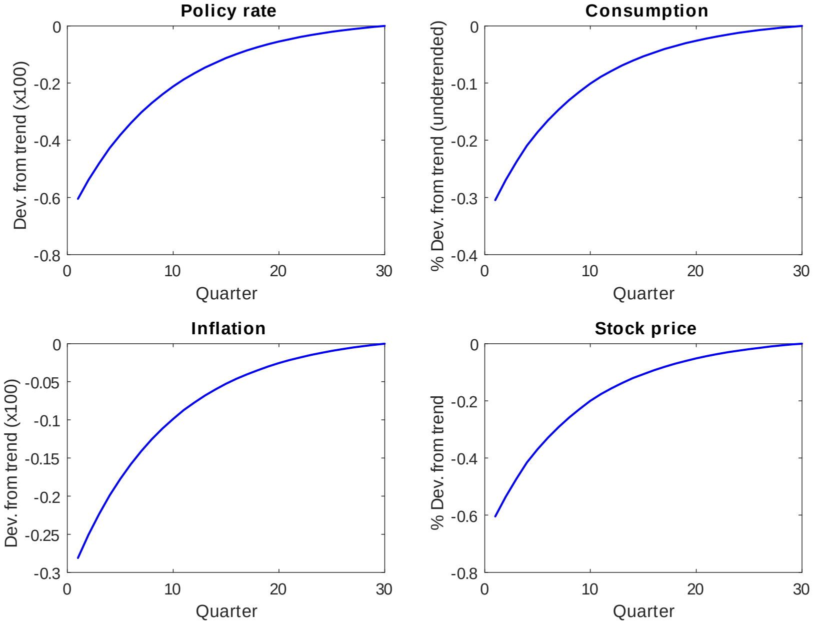

Figure 16: Impulse reponse to 1 standard deviation demand shock, far from the ZLB.

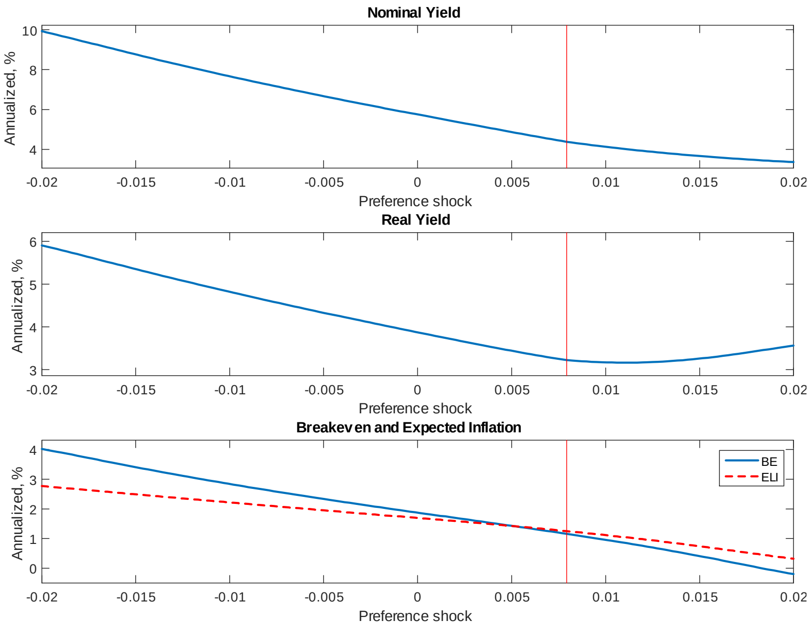

Figure 17: Policy function of long-term nominal and real yield and long-term breakeven and expected inflation, as a function of the preference shock.

The blue line corresponds to the IRF shown above (effect of a demand shock if the economy starts far from the ZLB). The red line demonstrates that the economy responds very differently to the same shock if it starts at the ZLB. Specifically, the interest rate cannot respond near the ZLB. This leads consumption and inflation to drop much more significantly. Clearly, the covariance of consumption and inflation implied by this shock is much larger at the ZLB. As a result, stock prices fall since dividends (assumed to be proportional to consumption) fall.

5.3.2 Productivity shocks

We now demonstrate how the ZLB affects the propagation of productivity shocks. Figure 19 displays the effect of 1-standard-deviation productivity shock when the economy is at the ZLB and when it is off the ZLB. In normal times, higher TFP leads to higher consumption, lower inflation, and a lower interest rate. However, when the ZLB binds, consumption falls, and inflation falls much more significantly. (Consumption may increase less instead of fall on impact, depending on parameter values.) In general, the overall effect on the covariance of consumption and inflation is uncertain, but it tends to increase (become positive or less negative) for most parameter values. Stock prices also tend to decline (or increase less) at the ZLB as they mimic the path of consumption.[24]

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paths when the economy starts in the nonstochastic steady-state and the shock sequence follow a deterministic process corresponding to the AR(1) shock. (There is a difference because the model is nonlinear.)

[24] There is a large debate in the macroeconomics literature debating the empirical relevance of these model dynamics (e.g.Wieland (2014)). However, it is important to note that for the purpose of this paper, we do not actually require that consumption falls with positive productivity shocks. It is enough that consumption increases less, and inflation decreases more, to affect the key covariance of consumption and inflation.

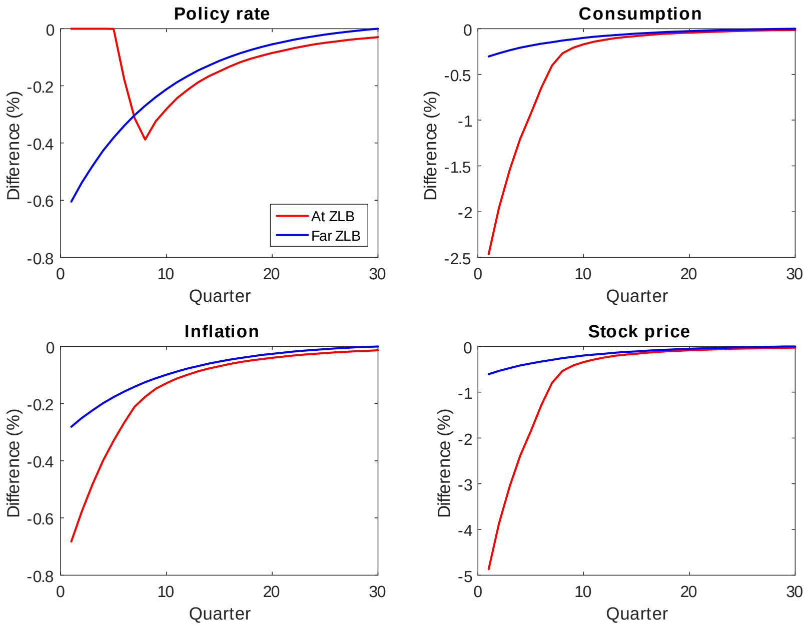

Figure 18: Impulse response to a 1 standard deviation demand shock when the economy is at the ZLB vs. in steady-state.

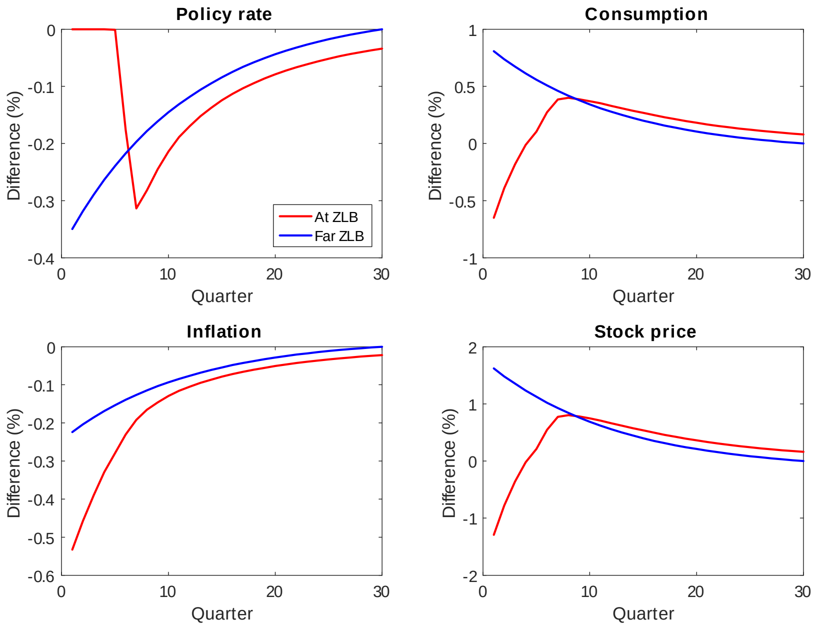

Figure 19: Impulse response to a 1 standard deviation productivity shock when the economy is at the ZLB vs. in steady-state.

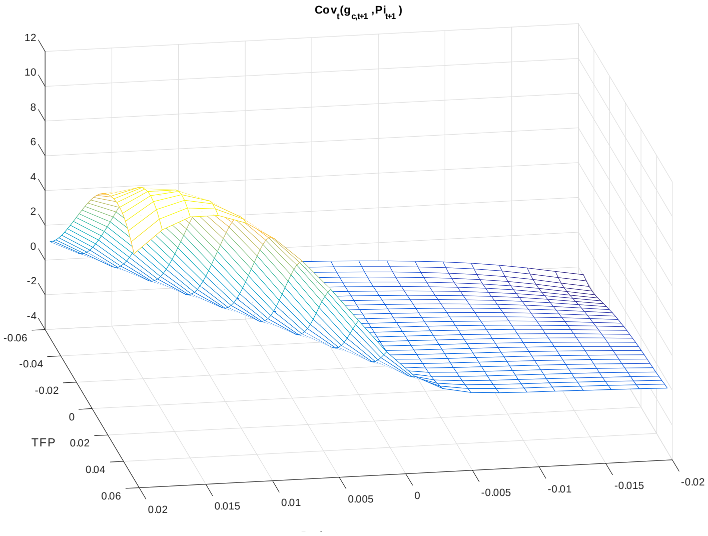

Figure 20: Conditional covariance of consumption growth and inflation next period, given the current state variables (TFP and preference shocks).

5.4 ZLB and risk premia

The key result of this paper is that the covariance of consumption and inflation changes as the economy operates closer to (or deeper into) the ZLB territory. To illustrate this, we calculate the conditional covariance of consumption growth and inflation and plot it in figure 20 against the current value of the state variables (TFP and preference shocks; note that the ZLB binds when the economy is in the Southwest quadrant). We see that in normal times, the covariance is negative, but it rises substantially when the economy operates close to the ZLB.[25]

Figure 21 depicts the inflation risk and term premia for a 10-year equivalent consol, and shows that it is positive in normal times, but becomes smaller when the economy is close to the ZLB. This reflects the large change in the conditional covariance of consumption and inflation together with the high risk aversion. The nominal and real term premium also tend to fall as the economy becomes closer to or deep into the ZLB territory.

To understand the change in nominal and real bond premia, recall that the TFP shock generates a positive bond premium while the preference shock generates a negative one. At the ZLB, consumption reacts much more to the preference shock, which tends to increase the magnitude of the preference-shock induced risk premium (more negative). Inversely, consumption becomes less sensitive to TFP (as seen in the policy functions), which reduces the term premium from the TFP shock. On top of that, inflation becomes more procyclical as discussed above. Overall, these effects tend to reduce bond premia.

An alternative way to depict these changing moments is to use contour plots; see figure 22.

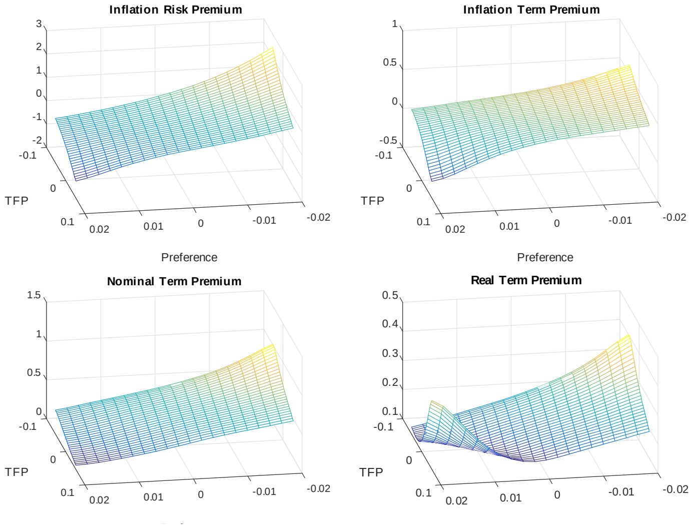

Figure 21: Inflation risk premium, inflation term premium, nominal term premium, and real term premium, as a function of the current state variables (TFP and preference shocks).

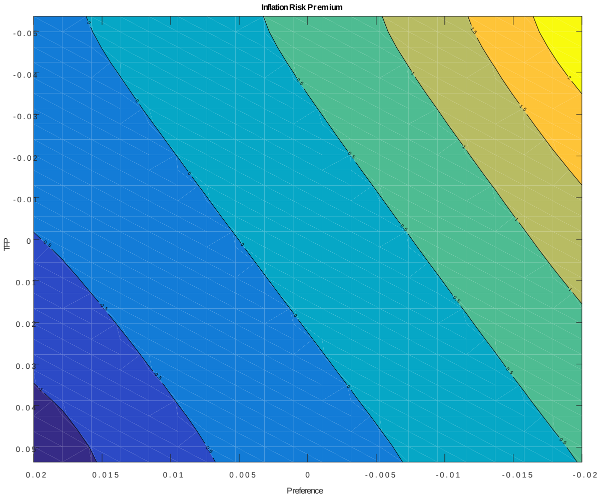

Figure 22: Inflation risk premium as a function of TFP and preference shocks.

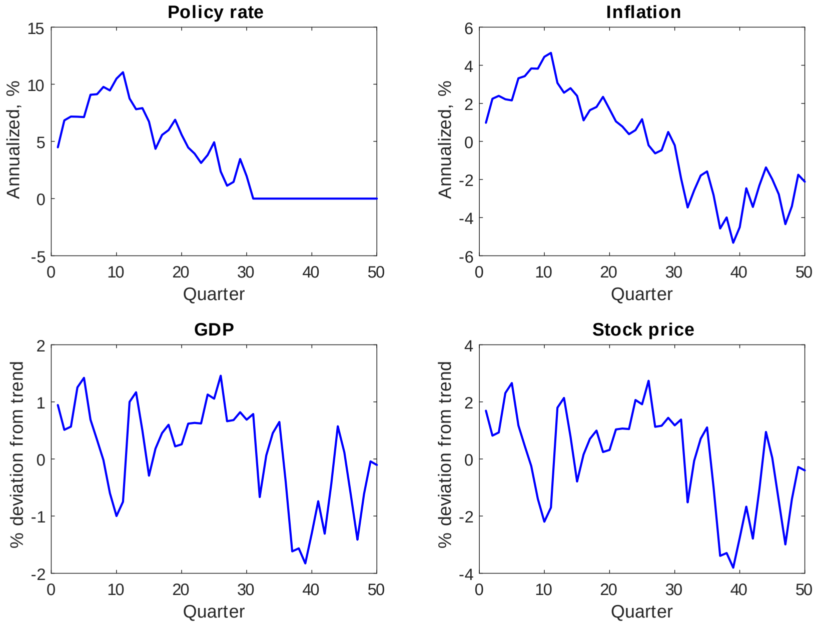

Figure 23: Macroeconomic variables

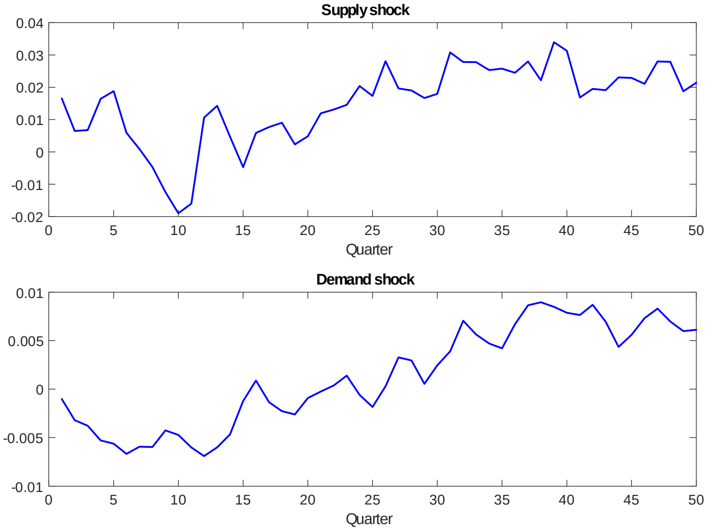

Figure 24: Shocks

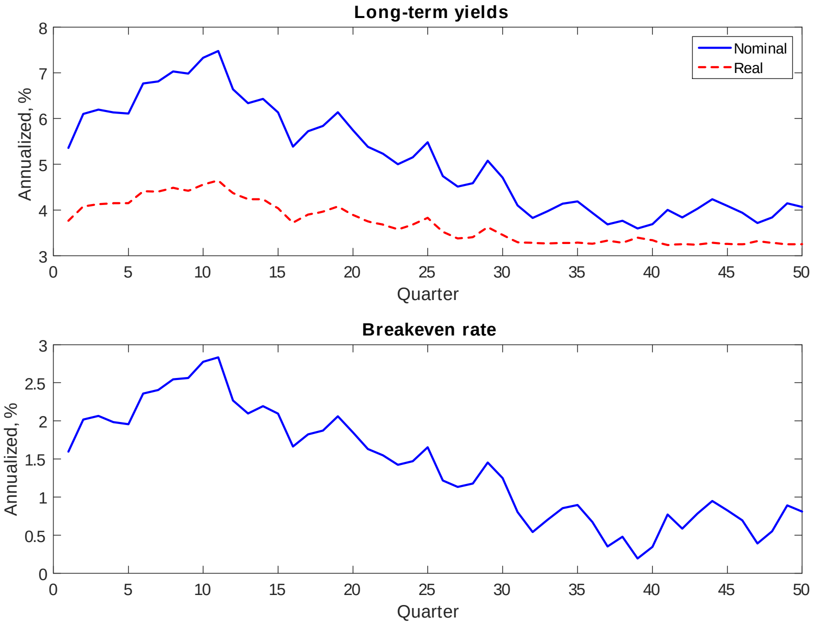

Figure 25: Long-term yields and breakeven

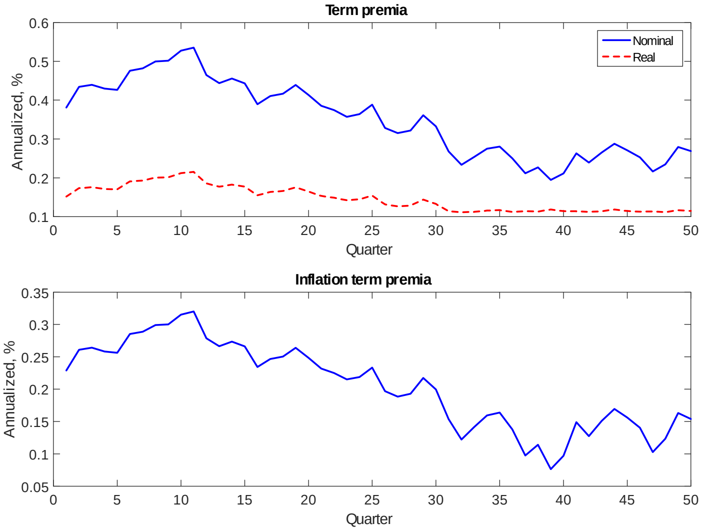

Figure 26: Term premia

	Full sample		$i \leq -4\%$		$i \leq -2\%$		$i \leq 0\%$		$i \leq 2\%$		$i \leq 4\%$		$i \geq 4\%$	
	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd
ΔlogY	0.00	1.60	1.74	3.57	0.58	2.17	0.35	1.80	0.08	1.64	-0.15	1.50	0.34	1.84
ΔlogN	-0.00	1.18	0.72	2.04	-0.32	0.73	-0.34	0.79	-0.14	0.89	0.18	1.42	1.37	2.58
π	1.69	1.67	-7.32	1.07	-4.64	0.62	-2.06	0.69	0.82	0.83	3.07	0.86	6.27	0.70
$y^{\$(1)}$	5.44	2.91	0.00	0.00	0.00	0.00	0.05	0.21	3.78	1.70	7.86	1.74	13.59	1.51
$y^{\$(40)}$	5.77	0.89	3.41	0.09	3.68	0.07	4.09	0.14	5.25	0.46	6.52	0.53	8.38	0.45
$y^{(1)}$	3.73	1.48	6.30	0.99	3.91	0.54	1.74	0.54	2.86	0.98	4.88	1.01	7.74	0.93
$y^{(40)}$	3.89	0.38	3.58	0.13	3.34	0.05	3.27	0.06	3.66	0.22	4.20	0.26	4.99	0.24
$BE^{(40)}$	1.88	0.51	-0.16	0.21	0.34	0.12	0.83	0.13	1.58	0.25	2.32	0.28	3.39	0.22
Iinflation RP	0.19	0.20	-0.52	0.08	-0.35	0.04	-0.19	0.04	0.07	0.09	0.36	0.13	0.85	0.12
Nominal TP	0.41	0.07	0.16	0.02	0.21	0.01	0.27	0.02	0.38	0.03	0.47	0.03	0.60	0.03
Real TP	0.17	0.03	0.14	0.02	0.12	0.00	0.12	0.00	0.15	0.01	0.19	0.01	0.24	0.01

Table 8: Simulated moment. Column 1 and 2 give the mean and standard deviation. Columns 3-14 give the mean and standard deviation by subsamples defined by the Taylor rate.

5.5 Example of ZLB

5.6 Simulated moments

We now simulate the model assuming that the economy is driven by both TFP shocks and preference shocks. Table 8 reports the moments both in full sample and in a sample "deep in" the ZLB as well as "far" from the ZLB. We define the subsample based on the implied Taylor (1993) interest rate rule.[26] A key point from this table is that the inflation risk premium goes from 85bps in the sample "far" from ZLB to -52bps in the sample "close". This implies that a significant decline of breakeven from the first sample to the second is not driven by a decline in expected inflation. As the breakeven declines from 3.39% to -0.16%, or 355bps, we see that 137bps (=85-(-52)) correspond to risk premia and 218bps (=355-137) to expectations. We also see in this table that, consistent with the figures above, the nominal and real term premia are lower when the economy operates close to the ZLB - nominal term premia fall by 44bps, and real term premia by 10bps. Hence, the inflation term premium also falls by 34 (=44-10) bps. These magnitudes are significant.[27]

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[25] We verify that the covariance of stock returns and breakevens, or stock returns and inflation, also tends to rise when the economy becomes closer to the ZLB. This validates our empirical strategy.

[26] It has been noted for instance that the Taylor rule would have implied a nominal rate of around -5% in 2009.

[27] We tried different ways to see if the difference could be substantially larger. In one experiment, we start from two initial states, one far away from the ZLB, one deep in the ZLB territory such that the ZLB binds 15 periods on average. We document that the difference in term premium (inflation term premium) between two states is about 70bps (70bps). In another experiment, we simulate the economy 1000 run, each run has 30 periods starting from one of the initial states. We then compute the mean difference in term premium (and inflation term premium) for the two samples conditional on ZLB duration of at least 15 periods starting from the first period for the sample with the ZLB state. This method yields the difference in term premium (inflation term premium) of about 40bps (30bps), which is substantially large.

	Inflation		Change in Breakeven	
	Above ZLB	At ZLB	Above ZLB	At ZLB
Coeff.	-0.05	0.29	-1.15	4.04
R2	0.63	0.27	0.67	0.56
Obs	475573	24426	475573	24426

Table 9: Regression of stock return on inflation and change in breakeven rate. Results are based on simulated data.

Pane A. Stock Return on Change in Breakeven						
	$i^{TR} \leq -4\%$	$i^{TR} \leq -2\%$	$i^{TR} \leq 0\%$	$i^{TR} \leq 2\%$	$i^{TR} > 2\%$	$i^{TR} > 4\%$
Coeff.	8.954	7.036	3.733	-0.729	-1.478	-1.733
R^2	0.88	0.76	0.59	0.68	0.66	0.58
Obs	330	1993	18102	262032	213823	3719
Panel B. Stock Return on Inflation						
	$i^{TR} \leq -4\%$	$i^{TR} \leq -2\%$	$i^{TR} \leq 0\%$	$i^{TR} \leq 2\%$	$i^{TR} > 2\%$	$i^{TR} > 4\%$
Coeff.	0.618	0.469	0.413	-0.009	-0.015	0.006
R^2	0.09	0.02	0.34	0.66	0.59	0.42
Obs	330	1993	180102	262032	213823	3719

Table 10: Regression of stock return on inflation and change in breakeven rate. The results are based on simulated data

5.7 Regression

5.8 Effect of high risk aversion macroeconomic dynamics

Our model is a standard New Keynesian model with the ZLB, but with high risk aversion. How do these "nonstandard" preferences affect the responses of consumption and inflation, which have been studied extensively in the New Keynesian literature in models with low risk aversion?[28] In our current calibration, there is a small but significant effect of risk aversion on macro dynamics. The logic is as follows. When the economy hits the ZLB, macro volatility rises because the effect of preference shocks on consumption and inflation becomes larger. This higher volatility in turn leads to higher precautionary savings which reinforce the recession. This effect is stronger with high risk aversion. As a result, we observe that inflation and consumption fall more when the economy becomes closer to the ZLB in the case of high risk aversion, than in the case of low risk aversion. Figures 27 and 28 depict the response to preference shocks when the economy is far/close to the ZLB. We see that quantities fall by a larger amount in the model with high risk aversion.

Table 9 compares simulated moments for the case with high risk aversion and low risk aversion. Not surprisingly that without high risk aversion, we are not able to generate the term premia that match

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[28] As in Eggertsson and Woodford (2003) for instance.

	Pane A. Change in Breakeven on Stock Return					
	$i^{TR} \leq -4\%$	$i^{TR} \leq -2\%$	$i^{TR} \leq 0\%$	$i^{TR} \leq 2\%$	$i^{TR} > 2\%$	$i^{TR} > 4\%$
Coeff.	0.097	0.107	0.109	-0.053	-0.115	-0.164
R^2	0.91	0.82	0.50	0.05	0.19	0.46
Obs	330	1993	18102	262032	213823	3719

	Panel B. Inflation on Stock Return					
	$i^{TR} \leq -4\%$	$i^{TR} \leq -2\%$	$i^{TR} \leq 0\%$	$i^{TR} \leq 2\%$	$i^{TR} > 2\%$	$i^{TR} > 4\%$
Coeff.	0.080	0.042	0.105	-0.01	-0.018	0.004
R^2	0.98	0.98	0.90	0.50	0.93	0.99
Obs	330	1993	180102	262032	213823	3719

Table 11: Regression of inflation and change in breakeven rate on stock returns. The results are based on simulated data. Leverage=2, E104283.

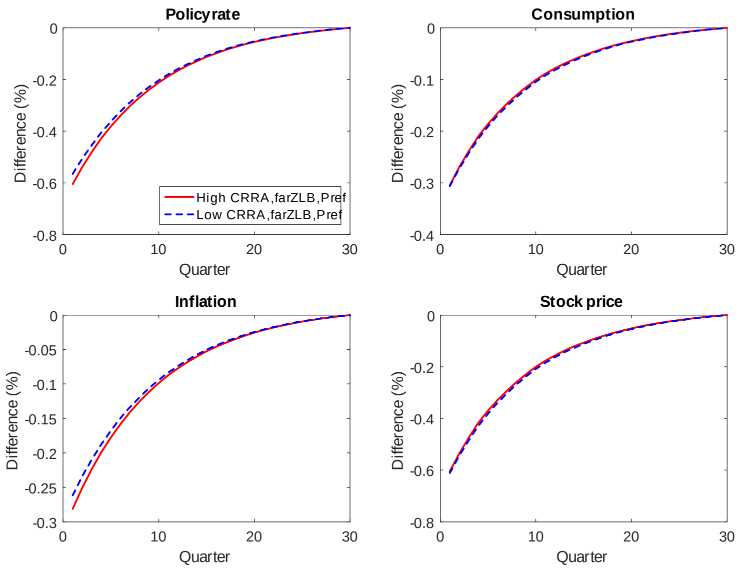

Figure 27: Comparison of responses to a preference shock for high and low risk aversion far from the ZLB.

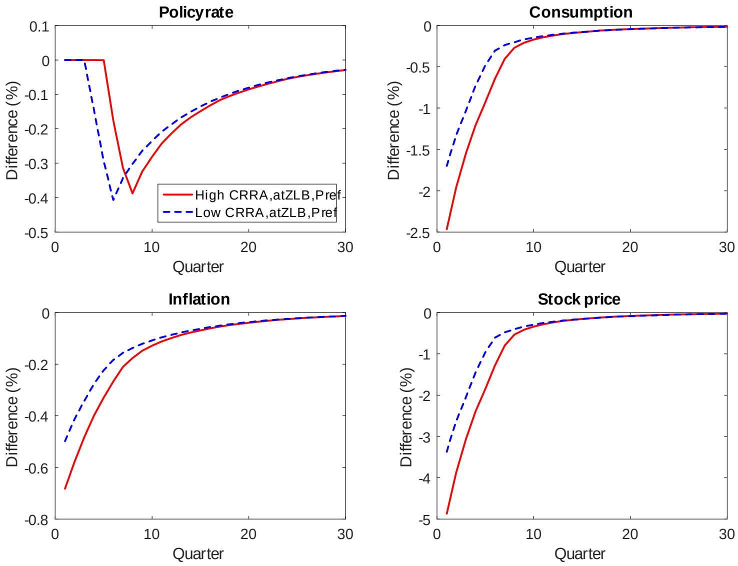

Figure 28: Comparison of responses to a preference shock for high and low risk aversion at the ZLB.

	Benchmark		Low risk aversion	
	Mean	Std	Mean	Std
ΔlogY	0.00	1.60	0.00	1.56
ΔlogN	-0.00	1.18	-0.00	1.27
π	1.69	1.67	1.96	1.52
$y^{\$(1)}$	5.44	2.91	5.94	2.81
$y^{\$(40)}$	5.77	0.89	5.85	0.82
$y^{(1)}$	3.73	1.48	3.99	1.48
$y^{(40)}$	3.89	0.38	3.97	0.38
$BE^{(40)}$	1.88	0.51	1.88	0.45
Inflation risk premium	0.19	0.20	-0.08	0.17
Nominal term premium	0.41	0.07	-0.00	0.00
Real term premium	0.17	0.03	0.00	0.00

Table 12: Simulated moment. Columns 1 and 2 give the mean and standard deviation under the benchmark calibraion with high risk aversion (CRRA=96 or $\alpha = -190$). Columns 3-4 give the mean and standard deviation for the model with low risk aversion (CRRA=0.85 or $\alpha = 0$).

the data. In particular, the yield curve in the case of low risk averion is sloping downward instead of upward. In addition, the term premia and inflation term premia are much smaller in this case.[29]

5.9 Role of Monetary Policy Rule

Monetary policy could do better. First, monetary policy could react to both the productivity shock and the demand shock in a more efficient way - and, absent the ZLB, could stabilize inflation (and the output gap) perfectly. Second, monetary policy could anticipate the possibility that the ZLB might bind, leading to sharper declines of interest rates close to the ZLB (Adam and Billi (2006)).

Exploring futher the implications of different monetary policy regimes is included in our future research plan.

6 Conclusion

Financial markets data suggest that inflation, while it is typically associated with bad economic outcomes, became associated with good outcomes post 2008. A simple New Keynesian model that incorporates the zero lower bound can rationalize this. Demand shocks have much larger effects on inflation and consumption at the ZLB than off the ZLB, when monetary policy can largely offset them. The comovement of inflation with output changes considerably in a way that attenuates inflation and term premia.

We plan to extend our study in a couple of directions. First, we will bring international evidence to bear on this question. Second, we plan to study the implications of different monetary policy rules. Finally, while the ZLB may be the most natural explanation of our empirical findings, alternative stories deserve to be explored quantitatively. For instance, it is plausible that higher inflation was perceived as beneficial because it facilitates household deleveraging.

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[29] The change in the covariance between consumption growth and inflation around the ZLB is much smaller. The differences in term premia between the far-from-ZLB sample and close-to-ZLB sample are also much smaller.

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8 Appendix

8.1 Detrended system

We denote with a $\widetilde{\ }$ the variables detrended by Z_t. That is,

$$\begin{aligned}\widetilde{C}_t &= \frac{C_t}{Z_t},\\ \widetilde{Y}_t &= \frac{Y_t}{Z_t},\end{aligned}$$

and so on. The system of equations to solve is hence:

(1) Taylor rule

$$Y_t^{\$,(1)} = \max\left\{1, Y^* \left(\frac{\Pi_t}{\Pi^*}\right)^{\phi_\pi} \left(\frac{\widetilde{GDP_t}}{GDP^*}\right)^{\phi_y} \beta_t^{\phi_\beta}\right\} \tag{14}$$

(2) Resource constraint:

$$\widetilde{C}_t = \left(1 - \frac{\phi}{2}(\Pi_t - \overline{\Pi})^2\right)\widetilde{Y}_t \tag{15}$$

(3) Production Function

$$\widetilde{Y}_t = N_t \tag{16}$$

(4) Phillips curve:

$$0 = (1 - \varepsilon + \varepsilon \widetilde{w}_t - \phi(\Pi_t - \Pi)\Pi_t)\,\widetilde{Y}_t + \phi E_t\left[e^{\Delta \log Z_{t+1}} M^{\$}_{t+1}(\Pi_{t+1} - \Pi)\Pi_{t+1}\widetilde{Y_{t+1}}\right] \tag{17}$$

(5) Euler equation

$$1 = E_t\left[Y_t^{\$,(1)} M^{\$}_{t+1}\right] \tag{18}$$

(6) Labor supply

$$\widetilde{w}_t = \chi N_t^{\nu} \widetilde{C}_t^{\sigma} \tag{19}$$

(7) Utility - in this case we define

$$\widetilde{V}_t = \frac{V_t}{Z_t^{1-\sigma}}$$

and we now have:

$$\widetilde{V}_t = \left(1 - \overline{\beta}\right)\left(\frac{\widetilde{C}_t^{1-\sigma}}{1-\sigma} - \frac{\chi N_t^{1+\nu}}{1+\nu}\right) + \overline{\beta}\beta_t E_t\left(\widetilde{V}_{t+1}^{1-\alpha} e^{(1-\alpha)(1-\sigma)\Delta \log Z_{t+1}}\right)^{\frac{1}{1-\alpha}} \tag{20}$$

(8) Real SDF:

$$\begin{aligned}
M_{t,t+1} &= \overline{\beta}\beta_t\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}\left(\frac{V_{t+1}}{E_t\left(V_{t+1}^{1-\alpha}\right)^{\frac{1}{1-\alpha}}}\right)^{-\alpha}\\
&= \overline{\beta}\beta_t\left(\frac{\widetilde{C}_{t+1}}{\widetilde{C}_t}\right)^{-\sigma} e^{-\sigma \Delta \log Z_{t+1}}\left(\frac{\widetilde{V}_{t+1} e^{(1-\sigma)\Delta \log Z_{t+1}}}{E_t\left(\widetilde{V}_{t+1}^{1-\alpha} e^{(1-\alpha)(1-\sigma)\Delta \log Z_{t+1}}\right)^{\frac{1}{1-\alpha}}}\right)^{-\alpha}\\
&= \overline{\beta}\beta_t\left(\frac{\widetilde{C}_{t+1}}{\widetilde{C}_t}\right)^{-\sigma} e^{-(\sigma + \alpha(1-\sigma))\Delta \log Z_{t+1}}\left(\frac{\widetilde{V}_{t+1}}{E_t\left(\widetilde{V}_{t+1}^{1-\alpha} e^{(1-\alpha)(1-\sigma)\Delta \log Z_{t+1}}\right)^{\frac{1}{1-\alpha}}}\right)^{-\alpha}
\end{aligned} \tag{21}$$

(9) Nominal SDF:

$$M^{\$}_{t,t+1} = \frac{M_{t,t+1}}{\Pi_{t+1}} \tag{22}$$

(10) Definition of potential as measured by the Central Bank:

$$\widetilde{YPOT}_t = e^{\phi_{ybar}(\mu_z - \Delta \log Z_t)} \widetilde{YPOT}_{t-1}^{\phi_{ybar}} \widetilde{C}_t^{1-\phi_{ybar}} \tag{23}$$

The state variables are $YPOT_t$, $\Delta \log Z_t$, and $\log \beta_t$. This is a system of 12 equations (once we add the shock law of motion) in 12 unknowns:

$Y_t^{\$,(1)}; \widetilde{YPOT}_t; \widetilde{Y}_t; \widetilde{C}_t; N_t; M_{t+1}, M^{\$}_{t+1}, \widetilde{V}_t; \widetilde{w_t}, \Delta \log Z_t \ \log \beta_t$.

8.2 Calculation of asset prices

Recall that the stock is an asset with payoff $D_t = C_t^{\xi}$, and that the real stock price satisfies the recursion

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

so that if we define the P/D ratio as $q_t^s = \frac{P_t^s}{D_t^s}$,then we need to solve the recursion for the P-D ratio:

$$q_t^s = E_t \left[M_{t+1} \left(q_{t+1}^s + 1 \right) \frac{D_{t+1}}{D_t} \right],$$

and the return on equity from t to $t+1$ is

$$R_{t+1}^e = \frac{P_{t+1}^s + D_{t+1}}{P_t^s} = \frac{q_{t+1}^s + 1}{q_t^s} \frac{D_{t+1}}{D_t}.$$

We can define detrended dividend as

$$\widetilde{D}_t = \frac{D_t}{Z_t^{\xi}},$$

and hence

$$\widetilde{D}_t = \widetilde{C}_t^{\zeta},$$

and hence we can solve for the P-D ratio q_t^s (which is stationary, so no need for detrending) using the recursion

$$q_t^s = E_t \left[M_{t+1} \left(q_{t+1}^s + 1 \right) \frac{\widetilde{D}_{t+1}}{\widetilde{D}_t} e^{\xi \Delta \log Z_{t+1}} \right].$$

We could also define the detrended price

$$\widetilde{P_t^s} = \frac{P_t^s}{Z_t^{\xi}},$$

and use the recursion

$$\widetilde{P_t^s} = E_t \left[M_{t+1} \left(\widetilde{P_{t+1}^s} + \widetilde{D}_{t+1} \right) \right] e^{\zeta \Delta \log Z_{t+1}}.$$

All the quantities defined for bonds do not require detrending since interest rates and inflation are stationary.

8.3 Definition of asset price moments using zero-coupon bonds

In the paper we define asset pricing object (e.g., the term premium) using our “geometric consol” assets. For clarity and completeness, this section defines the same object for the more standard zero-coupons assets. Let $P_t^{(n)}$ the price of a zero coupon real bond (in real terms). We have

$$P_t^{(n)} = E_t\left(M_{t+1}P_{t+1}^{(n-1)}\right)$$

and $P_t^{(0)} = 1$, where M_{t+1} is the real SDF. We define the yield as

$$\frac{1}{\left(1+Y_t^{(n)}\right)^n} = P_t^{(n)}$$

In log, let $p_t^{(n)} = \log P_t^{(n)}$ and $y_t^{(n)} = \log\left(1+Y_t^{(n)}\right)$, then

$$y_t^{(n)} = -\frac{1}{n}p_t^{(n)}.$$

The holding period return of a bond of maturity n is defined as

$$R_{t+1}^{(n)} = \frac{P_{t+1}^{(n-1)}}{P_t^{(n)}}$$

We can have the same exact relationships with nominal yields. We denote them with a \$. Of course we need to use the nominal SDF, and the bond price is now the \$ price of a nominal bond.

The breakeven is defined as the difference of log yields:

$$BE_t^{(n)} = y_t^{\$(n)} - y_t^{(n)},$$

and the inflation risk premium is defined as the difference between breakevens and expected log inflation:

$$IRP_t^{(n)} = BE_t^{(n)} - ELI_t^{(n)}$$

where, denoting Q the price level:

$$ELI_t^{(n)} = E_t\left(\log\frac{Q_{t+n}}{Q_t}\right) = E_t\sum_{k=1}^{n}\pi_{t+k}$$

where $\pi_{t+1} = \log\left(\frac{Q_{t+1}}{Q_t}\right)$ is log inflation.

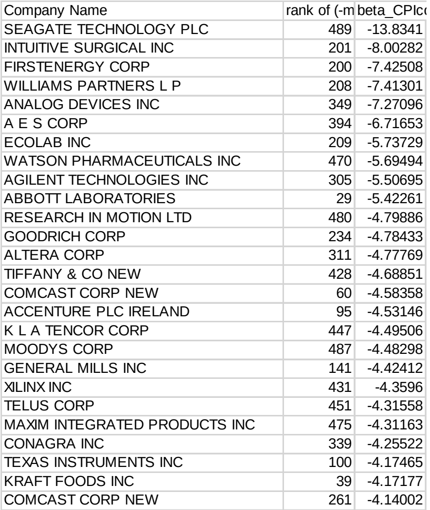
The term premium is defined as the difference between the log yield of a $n-$period bond and the expected short rate over n periods, for $n \geq 2$:

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

We can use this definition for nominal or for real term premia.

The inflation term premium is defined as be the difference between the nominal and real term premium. This is close, but not exactly equal, to the inflation risk premium. To see this, note that

$$\begin{aligned} ITP_t^{(n)} &= TP_t^{\$(n)} - TP_t^{(n)}, \\ &= y_t^{\$(n)} - y_t^{(n)} - \frac{1}{n}\sum_{k=0}^{n-1}E_t\left(y_{t+k}^{\$(1)} - y_{t+k}^{(1)}\right), \\ &= BE_t^{(n)} - \frac{1}{n}\sum_{k=0}^{n-1}E_t\left(BE_{t+k}^{(1)}\right), \end{aligned}$$



Company Name	rank of (-m	beta_CPIc
SEAGATE TECHNOLOGY PLC	489	-13.8341
INTUITIVE SURGICAL INC	201	-8.00282
FIRSTENERGY CORP	200	-7.42508
WILLIAMS PARTNERS L P	208	-7.41301
ANALOG DEVICES INC	349	-7.27096
A E S CORP	394	-6.71653
ECOLAB INC	209	-5.73729
WATSON PHARMACEUTICALS INC	470	-5.69494
AGILENT TECHNOLOGIES INC	305	-5.50695
ABBOTT LABORATORIES	29	-5.42261
RESEARCH IN MOTION LTD	480	-4.79886
GOODRICH CORP	234	-4.78433
ALTERA CORP	311	-4.77769
TIFFANY & CO NEW	428	-4.68851
COMCAST CORP NEW	60	-4.58358
ACCENTURE PLC IRELAND	95	-4.53146
K L A TENCOR CORP	447	-4.49506
MOODYS CORP	487	-4.48298
GENERAL MILLS INC	141	-4.42412
XILINX INC	431	-4.3596
TELUS CORP	451	-4.31558
MAXIM INTEGRATED PRODUCTS INC	475	-4.31163
CONAGRA INC	339	-4.25522
TEXAS INSTRUMENTS INC	100	-4.17465
KRAFT FOODS INC	39	-4.17177
COMCAST CORP NEW	261	-4.14002

and since $y^{\$(1)}_{t+k} - y^{(1)}_{t+k} = BE^{(1)}_{t+k} = IRP^{(1)}_{t+k} + ELI^{(1)}_{t+k}$, we have

$$ITP^{(n)}_t = BE^{(n)}_t - \frac{1}{n}\sum_{k=0}^{n-1} E_t\left(IRP^{(1)}_{t+k} + ELI^{(1)}_{t+k}\right)$$

and since $ELI^{(n)}_t = E_t \sum_{k=1}^{n} \pi_{t+k} = E_t \sum_{k=1}^{n} ELI^{(1)}_{t+k}$, we have

$$\begin{aligned} ITP^{(n)}_t &= BE^{(n)}_t - ELI^{(n)}_t - \frac{1}{n}\sum_{k=0}^{n-1} E_t\left(IRP^{(1)}_{t+k}\right) \\ &= IRP^{(n)}_t - \frac{1}{n}\sum_{k=0}^{n-1} E_t\left(IRP^{(1)}_{t+k}\right). \end{aligned}$$

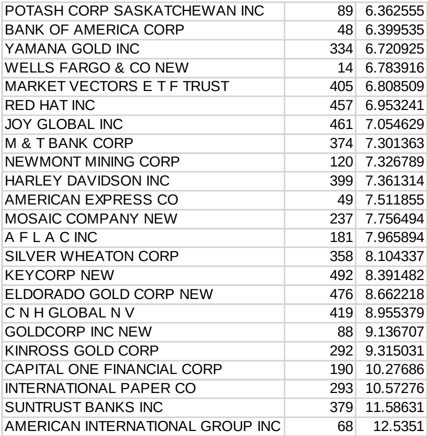
In the case where the inflation risk premium is constant, then $ITP^{(n)}_t = IRP^{(n)}_t - IRP^{(1)}_t$. Generally, since the inflation risk premium is thought to be small at short horizons $IRP^{(1)}_t \simeq 0$, and the difference between the inflation term premium and the inflation risk premium ought to be small.

8.4 Numerical method

Our numerical method follows Miao and Ngo (2015) and Fernandez-Villaverde et al. (2012). We use projection methods with cubic splines. (Details to be added.)

8.5 List of stocks

Lowest inflation betas as of 2011Highest inflation betas as of 2011



POTASH CORP SASKATCHEWAN INC	89	6.362555
BANK OF AMERICA CORP	48	6.399535
YAMANA GOLD INC	334	6.720925
WELLS FARGO & CO NEW	14	6.783916
MARKET VECTORS E T F TRUST	405	6.808509
RED HAT INC	457	6.953241
JOY GLOBAL INC	461	7.054629
M & T BANK CORP	374	7.301363
NEWMONT MINING CORP	120	7.326789
HARLEY DAVIDSON INC	399	7.361314
AMERICAN EXPRESS CO	49	7.511855
MOSAIC COMPANY NEW	237	7.756494
A F L A C INC	181	7.965894
SILVER WHEATON CORP	358	8.104337
KEYCORP NEW	492	8.391482
ELDORADO GOLD CORP NEW	476	8.662218
C N H GLOBAL N V	419	8.955379
GOLDCORP INC NEW	88	9.136707
KINROSS GOLD CORP	292	9.315031
CAPITAL ONE FINANCIAL CORP	190	10.27686
INTERNATIONAL PAPER CO	293	10.57276
SUNTRUST BANKS INC	379	11.58631
AMERICAN INTERNATIONAL GROUP INC	68	12.5351