Federal Reserve Bank of Chicago

Risk Management for Monetary Policy Near the Zero Lower Bound

Charles Evans, Jonas Fisher, François Gourio, and Spencer Krane

May 2015

WP 2015-03

Risk Management for Monetary Policy
Near the Zero Lower Bound[*]

Charles Evans   Jonas Fisher   François Gourio   Spencer Krane

May 21, 2015

Abstract

As projections have inflation heading back toward target and the labor market continuing to improve, the Federal Reserve has begun to contemplate an increase in the federal funds rate. There is however substantial uncertainty around these projections. How should this uncertainty affect monetary policy? In many standard models uncertainty has no effect. In this paper, we demonstrate that the zero lower bound on nominal interest rates implies that the central bank should adopt a looser policy when there is uncertainty. In the current context this result implies that a delayed liftoff is optimal. We demonstrate this result theoretically in two canonical macroeconomic models. Using numerical simulations of our models, calibrated to the current environment, we find optimal policy calls for 2 to 3 quarters delay in liftoff relative to a policy that does not take into account uncertainty about policy being constrained by the ZLB. We then use a narrative study of Federal Reserve communications and estimated policy reaction functions to show that risk management is a longstanding practice in the conduct of monetary policy.

JEL Classification Numbers: E52, E58
Keywords: monetary policy, risk management, zero lower bound

1 Introduction

To what extent should uncertainty affect monetary policy? This classic question is relevant today as the Fed considers when to start increasing the federal funds rate. In the March 2015 Summary of Economic Projections, most Federal Open Market Committee (FOMC) participants forecast that the unemployment rate will return to its long-run neutral level by late 2015 and that inflation will gradually rise back to its 2 percent target. This forecast could go wrong in two ways. One is that the FOMC may be overestimating the underlying strength in the economy or the tendency of inflation to return to target. Guarding against these risks calls for cautious removal of accommodation. The second is that the economy could be poised for stronger growth and inflation than currently projected. This risk calls for more aggressive rate hikes. How should policy manage these divergent risks?

If the FOMC misjudges the impediments to growth and inflation and reduces monetary accommodation too soon, it could find itself in the uncomfortable position of having to reverse course and being constrained by the zero lower bound (ZLB) again. It is true the FOMC has access to unconventional policy tools at the ZLB, but these appear to be imperfect substitutes for the traditional funds rate instrument. In contrast, if the Fed keeps rates too low and inflation rises too quickly, it most likely could be brought back into check with modest increases in interest rates. Since the unconventional tools available to counter the first scenario may be less effective than the traditional tools to counter the second scenario, the costs of premature liftoff may exceed those of delay. It therefore seems prudent to refrain from raising rates until the FOMC is highly certain that growth is sustainable and inflation is returning to target.[1]

In this paper we establish theoretically that uncertainty about monetary policy being constrained by the ZLB in the future implies an optimally looser policy, which in the current context means delaying liftoff – the risk management framework just described. We formally define risk management as the principle that policy should be formulated taking into account the dispersion of shocks around their means. Our main theoretical contribution is to provide

---

[1] Evans (2014)'s speech at the Petersen Institute of Economics discusses these issues at greater length.

a simple demonstration, using standard models of monetary policy, that the ZLB implies a new role for such risk management through two distinct economic channels.

The first channel - which we call the *expectations channel* – arises because the possibility of a binding ZLB tomorrow leads to lower expected inflation and output today, and hence dictates some counteracting policy easing today. The second channel – which we call the *buffer stock* channel – arises because, if inflation or output are intrinsically persistent, building up output or inflation today reduces the likelihood and severity of hitting the ZLB tomorrow. Optimal policy when either of these channels is operative should be looser at times when a return to the ZLB remains a distinct possibility. In simulations calibrated to the current environment we find that optimal policy prescribes 2 to 3 quarters of delay in liftoff relative to a policy that does not take this uncertainty into account. However under the optimal policy the central bank must be prepared to raise rates quickly as the threat of being constrained by the ZLB recedes.

Would it be unusual for the Fed to take into account uncertainty in setting its policy rate? The second part of the paper argues that risk management has been a longstanding practice in U.S. monetary policy. Therefore advocating it in the current policy environment would be consistent with a well-established approach of the Federal Reserve. Of course, because the ZLB was not until recently perceived as an important constraint, the theoretical rationales for risk management were different in the past. It is true that in a wide class of models that abstract from the ZLB, optimal policy involves adjusting the interest rate in response to the mean of the distribution of shocks and information on higher moments is irrelevant (the so-called "certainty equivalence" principle.) However, there is an extensive literature covering departures from this result based on nonlinear economic environments or uncertain policy parameters that justify taking a risk management approach away from the ZLB.

We explore whether policy-makers have actually practised risk management prior to the ZLB period in two ways. First, we analyze Federal Reserve communications over the period 1987-2008 and find numerous examples when uncertainty or the desire to insure against im-

portant risks to the economy were used to help explain the setting of policy. Confirmation of this view is found in Greenspan (2004) who states "...the conduct of monetary policy in the United States has come to involve, at its core, crucial elements of risk management." Second, we estimate a conventional forecast-based monetary policy reaction function augmented with a variety of measures of risk based on financial market data, Federal Reserve Board staff forecasts, private-sector forecasts, and narrative analysis of the FOMC minutes. We find clear evidence that when measured in this way risk has had a statistically and economically significant impact on the interest rate choices of the FOMC. Thus, risk management appears to be old hat for the FOMC.

If the monetary policy toolkit contained alternative instruments that were perfect substitutes for changing the policy rate, then the ZLB would not present any special economic risk and our analysis would be moot. We do not think this is the case. Even though most central bankers believe unconventional policies such as large scale asset purchases (LSAPs) or more explicit and longer-term forward guidance about policy rates can provide considerable accommodation at the ZLB, few argue that these tools are on an equal footing with traditional policy instruments.[2]

One reason for this is that effects of unconventional policies on the economy naturally are much more uncertain than those of traditional tools. There are divergent empirical estimates of the effects and uncertainty about the theoretical mechanism behind those effects. Various studies of LSAPs, for example, provide a wide range of estimates of their ability to put downward pressure on private borrowing rates and influence the real economy. Furthermore, the effects of both LSAPs and forward guidance on interest rates are complicated functions of private-sector expectations, which makes their economic effects highly uncertain as well.[3]

---

[2]For example, while there is econometric evidence that changes in term premia influence activity and inflation, some studies find the effects appear to be less powerful than comparably sized movements in the short term policy rate, see D'Amico and King (2015), Kiley (2012) and Chen, Curida, and Ferrero (2012).

[3]Bomfin and Meyer (2010), D'Amico and King (2013) and Gagnon, Raskin, Remache, and Sack (2010) find noticeable effects of LSAPs on Treasury term permia while Chen et al. (2012) and Hamilton and Wu (2010) unearth only small effects. Krishnamurthy and Vissing-Jorgensen (2013) argue that the LSAPs have only had a substantial influence on private borrowing rates in the mortgage market. Engen, Laubach, and Reifschneider (2015) and Campbell, Evans, Fisher, and Justiniano (2012) analyze the interactions between LSAPs, forward guidance, and private sector expectations.

Uncertainty about the transmission mechanism of LSAPs is reflected in Krishnamurthy and Vissing-Jorgensen (2013)'s discussion of the various hypotheses that have been proposed.

Unconventional tools also carry potential costs. The four most commonly cited are: the large increases in reserves generated by LSAPs risk unleashing inflation; a large balance sheet may make it more difficult for the Fed to raise interest rates when the time comes; the extended period of very low interest rates and Federal Reserve intervention in the long-term Treasury and mortgage markets may induce inefficient allocation of credit and financial fragility; and the large balance sheet puts the Federal Reserve at risk of incurring financial losses if rates rise too quickly and such losses could undermine its support and independence.[4] Costs reduce the incentive to use any policy tool. The costs of unconventional tools also are very hard to quantify, and so naturally elevate the level of uncertainty associated with them.

A consequence of this uncertainty over the benefits and costs of unconventional tools is that they are likely to be used more cautiously than traditional policy instruments, as suggested by the classic Brainard (1967) analysis. For example Bernanke (2012) emphasizes that because of the uncertain costs and benefits of them "...the hurdle for using unconventional policies should be higher than for traditional policies." In addition, at least conceptually, some of the benefits of unconventional policies may be decreasing, and the costs increasing, in the size of the balance sheet or in the amount of time spent in a very low interest rate environment.[5] Accordingly, policies that had wide-spread support early on in a ZLB episode might be difficult to extend or expand with an already large balance sheet.

So, while valuable, unconventional policies also appear to be less-than-perfect substitutes for changes in short term policy rates. Accordingly, the ZLB presents a different set of risks to policymakers than those that they face during more conventional times and thus it is

---

[4]These costs are mitigated, however, by additional tools the Fed has introduced to exert control over interest rates when the time comes to exit the ZLB and by enhanced supervisory and regulatory efforts to monitor and address potential financial stability concerns. Furthermore, continued low rates of inflation and contained private-sector inflationary expectations have reduced concerns regarding an outbreak of inflation.

[5]Krishnamurthy and Vissing-Jorgensen (2013) argue successive LSAP programs have had a diminishing influence on term premia. Surveys conducted by Blue Chip and the Federal Reserve Bank of New York also indicate that market participants are less optimistic that further asset purchases would provide much stimulus if the Fed was forced to expand their use in light of unexpected economic weakness.

worthy of consideration on its own accord. We abstract from unconventional policy tools for the remainder of our analysis.

2 Rationales for risk management near the ZLB

The canonical framework of monetary policy analysis assumes that the central bank sets the nominal interest rate to minimize a quadratic loss function of the deviation of inflation from its target and the output gap, and that the economy is described by a set of linear equations. In most applications, uncertainty is incorporated as additive shocks to these linear equations, capturing factors outside the model that lead to variation in economic activity or inflation.[6] A limitation of this approach is that, by construction, it denies that a policymaker might choose to adjust policy in the face of changes in uncertainty about economic fundamentals. However, the evidence discussed below in Sections 3 and 4 suggests that in practice policymakers are sensitive to uncertainty and respond by following what appears to be a risk management approach. Motivating why a central banker should behave in this way requires some departure from the canonical framework. The main contribution of this section is to consider a departure associated with the possibility of a binding ZLB in the future.

We show that when a policymaker might be constrained by the ZLB in the future, optimal policy today should take account of uncertainty about fundamentals. We focus on two distinct channels through which this can occur. First we use the workhorse forward-looking New Keynesian model to illustrate the *expectations channel*, in which the possibility of a binding ZLB tomorrow leads to lower expected inflation and an output gap occurring today, thus necessitating policy easing today. We then use a backward-looking "Old" Keynesian set-up to illustrate the *buffer stock channel*, in which it can be optimal to build up output or inflation today in order to reduce the likelihood and severity of being constrained by the

---

[6]This framework can be derived from a micro-founded DSGE model (see for instance Woodford (2003), Chapter 6), but it has a longer history and is used even in models that are not fully micro-founded. The Federal Reserve Board staff routinely conducts optimal policy exercises in the FRB/US model, see for example English, López-Salido, and Tetlow (2013).

ZLB tomorrow. Both of these channels operate in modern DSGE models such as Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007), but they are more transparent if we consider them in separate, although related, models. After describing these two channels we construct some numerical simulations to assess their quantitative effects.

2.1 The expectations channel

The simple New Keynesian model has well established micro-foundations based on price stickiness. Given that there are many excellent expositions of these foundations, *e.g.* Woodford (2003) or Gali (2008), we just state our notation without much explanation. The model consists of two main equations, the *Phillips curve* and the *IS curve*.

The Phillips curve is specified as

$$\pi_t = \kappa x_t + \beta E_t \pi_{t+1} + u_t, \tag{1}$$

where π_t and x_t are both endogenous variables and denote inflation and the output gap at date t; E_t is the date t conditional expectations operator with rational expectations assumed; u_t is a mean zero exogenous *cost-push* shock; and $0 < \beta < 1$, $\kappa > 0$. For simplicity we assume the central bank has a constant inflation target equal to zero so π_t is the deviation of inflation from that target. The cost-push shock represents exogenous changes to inflation such as an independent decline in inflation expectations, dollar appreciation or changes in oil prices.

The IS curve is specified as

$$x_t = E_t x_{t+1} - \frac{1}{\sigma} \left(i_t - E_t \pi_{t+1} - \rho_t^n \right), \tag{2}$$

where $\sigma > 0$, i_t is the nominal interest rate controlled by the central bank, and ρ_t^n is the *natural rate of interest* given by

$$\rho_t^n = \bar{\rho} + \sigma g_t + \sigma E_t(z_{t+1} - z_t). \tag{3}$$

The variable g_t is an exogenous mean zero *demand* shock, and z_t is the exogenous log of potential output. Since z_t and g_t are exogenous, so is the natural rate. Equation (2) indicates that ρ_t^n corresponds to the setting of the nominal interest rate consistent with expected inflation at target and the output gap equal to zero.[7] If potential output is constant and the demand shock equals zero, then the natural rate equals the constant $\bar{\rho} > 0$.

Our analysis is centered around uncertainty in the natural rate.[8] From (3) we see that this uncertainty derives from uncertainty about g_t and $E_t(z_{t+1} - z_t)$. We interpret the former as arising due to a variety of factors, including fiscal policy, foreign economies' growth, and financial considerations such as de-leveraging.[9] The latter source of uncertainty is over the variety of factors that can influence the expected rate of growth in potential output, for example as emphasized in the recent debate over "secular stagnation."

We adopt the canonical framework in assuming the central bank acts to minimize a quadratic loss function with the understanding that private-sector behavior is governed by (1)–(3). The loss function is

$$L = \frac{1}{2} E_0 \sum_{t=0}^{\infty} \beta^t \left(\pi_t^2 + \lambda x_t^2 \right), \tag{4}$$

where $\lambda \geq 0$. We further assume the ZLB constraint, *i.e.* $i_t \geq 0$, abstracting from the possibility that the effective lower bound on i_t is slightly negative. The short term interest rate is the central bank's only policy instrument and it is set by solving for optimal policy under *discretion*. In particular, each period the central bank sets the nominal interest rate with the understanding that private agents anticipate that it will re-optimize in the following periods.

---

[7]Woodford (2003, p. 248) defines the natural rate as the equilibrium real rate of return in the case of fully flexible prices. As discussed by Barsky, Justiniano, and Melosi (2014), in medium-scale DSGE models with many shocks the appropriate definition of the natural rate is less clear.

[8]There is ample evidence of considerable uncertainty regarding the natural rate. See for example Barsky et al. (2014), Hamilton, Harris, Hatzius, and West (2015) and Laubach and Williams (2003).

[9]Uncertainty itself could give rise to g_t shocks. A large amount of recent work, following Bloom (2009), suggests that private agents react to increases in economic uncertainty, leading to a decline in economic activity. One channel is that higher uncertainty may lead to precautionary savings which depresses demand, as in emphasized by Basu and Bundick (2013), Fernández-Villaverde, Guerró-Quintana, Kuester, and Rubio-Ramírez (2012) and Born and Pfeifer (2014).

We focus on optimal policy under discretion for two reasons. First, the case of commitment with a binding ZLB already has been studied extensively. In particular it is well known from the contributions of Krugman (1998), Egertsson and Woodford (2003), Woodford (2012) and Werning (2012) that commitment can reduce the severity of the ZLB problem by creating higher expectations of inflation and the output gap. One implication of these studies is that the central bank should commit to keeping the policy rate at zero longer than would be prescribed by discretionary policy. By studying optimal policy under discretion we find a different rationale for a policy of keeping rates "lower for longer" that does not rely on the central bank having the ability to commit to a time-inconsistent policy.[10] Nevertheless below we discuss intuition for why our main result should extend to the case of commitment. Second, this approach may better approximate the institutional environment in which the FOMC operates.

2.1.1 A ZLB scenario

We study optimal policy when the central bank is faced with the following simple ZLB scenario. The central bank observes the current value of the natural rate, ρ_0^n, and the cost-push shock u_0; moreover, there is no uncertainty in the natural rate after $t = 2$, $\rho_t^n = \bar{\rho} > 0$ for all $t \geq 2$, nor in the cost push shock after $t = 1$, $u_t = 0$ for all $t \geq 1$. However, there is uncertainty at $t = 1$ regarding the natural rate ρ_1^n.[11] The variable ρ_1^n is assumed to be distributed according to the probability density function $f_\rho(\cdot)$.

This very simple scenario keeps the optimal policy calculation tractable while preserving the main insights. We also think it captures some key elements of uncertainty faced by the FOMC today. We do not have to take a stand on whether the ZLB is binding before $t = 0$. One possibility is that the natural rate ρ_t^n was sufficiently negative for $t < 0$ so that the

---

[10]Implicitly we are assuming the central bank does not have the ability to employ what Campbell et al. (2012) call "Odyssean" forward guidance. However our model is consistent with the central bank using forward guidance in the "Delphic" sense they describe because agents anticipate how the central bank reacts to evolving economic conditions.

[11]It is easy to verify that if the uncertainty about the natural rate is only at $t = 0$ the optimal policy would be to set the interest rate to the expected value of the natural rate and and the amount of uncertainty would have no affect. This is why our scenario has more than two periods.

optimal policy rate was set at zero, $i_t = 0$, for $t < 0$, but the economy has been improving so that by $t = 0$ the natural rate is close to zero. The question is whether to raise the policy rate at $t = 0$, $t = 1$ or $t = 2$. Our formulation allows us to consider this optimal timing of liftoff.

2.1.2 Analysis

To find the optimal policy, we solve the model backwards from $t = 2$ and focus on the policy choice at $t = 0$. First, for $t \geq 2$, it is possible to perfectly stabilize the economy by setting the nominal interest rate equal to the (now positive) natural rate, $i_t = \rho_t^n = \bar{\rho}$. This leads to $\pi_t = x_t = 0$ for $t \geq 2$.[12] The optimal policy at $t = 1$ will depend on the realized value of the natural rate ρ_1^n. If $\rho_1^n \geq 0$, then it is again possible (and optimal) to perfectly stabilize by setting $i_1 = \rho_1^n$, leading to $x_1 = \pi_1 = 0$. However if $\rho_1^n < 0$, the ZLB binds and consequently $x_1 = \rho_1^n/\sigma < 0$ and $\pi_1 = \kappa \rho_1^n/\sigma < 0$. The expected output gap at $t = 1$ is hence $E_0 x_1 = \int_{-\infty}^{0} \rho f_\rho(\rho) d\rho / \sigma \leq 0$ and expected inflation is $E_0 \pi_1 = \kappa E_0 x_1 < 0$.

Because agents are forward-looking, this low expected output gap and inflation feed backward to $t = 0$. A low output gap tomorrow depresses output today by a wealth effect via the IS curve. Low inflation tomorrow depresses inflation today since price setting is forward looking in the Phillips curve and also depresses output today by raising the real interest rate via the IS curve. The optimal policy at $t = 0$ must take into account these effects. This implies that optimal policy will be looser than if there was no chance that the ZLB binds tomorrow.

Mathematically, substituting for π_0 and i_0 using (1) and (2), and taking into account the ZLB constraint, optimal policy at $t = 0$ solves the following problem:

$$\min_{x_0} \frac{1}{2} \left((\kappa x_0 + \beta E_0 \pi_1 + u_0)^2 + \lambda x_0^2 \right) \text{ s.t. } x_0 \leq E_0 x_1 + \frac{1}{\sigma} (\rho_0^n + E_0 \pi_1). \tag{5}$$

---

[12]This simple interest rate rule implements the equilibrium $\pi_t = x_t = 0$, but is also consistent with other equilibria. However there are standard ways to rule out these other equilibria. See Gali (2008, pp. 76–77) for a discussion. Henceforth we will not consider this issue.

Two cases arise, depending on whether the ZLB binds at $t = 0$ or not. Define the threshold value

$$\rho_0^* = -\sigma \frac{\kappa}{\lambda + \kappa^2} u_0 - \left(1 + \frac{\kappa}{\sigma} + \beta \frac{\kappa^2}{\lambda + \kappa^2}\right) \int_{-\infty}^0 \rho f_\rho(\rho) d\rho. \tag{6}$$

If $\rho_0^n > \rho_0^*$, then the optimal policy is to follow the standard monetary policy response to an inflation shock to the Phillips curve, $\beta E_0 \pi_1 + u_0$, leading to:

$$x_0 = -\frac{\kappa}{\lambda + \kappa^2} \left(\beta E_0 \pi_1 + u_0\right); \quad \pi_0 = \frac{\lambda}{\lambda + \kappa^2} \left(\beta E_0 \pi_1 + u_0\right). \tag{7}$$

The corresponding interest rate is

$$\begin{aligned} i_0 &= \rho_0^n + E_0 \pi_1 + \sigma(E_0 x_1 - x_0), \\ &= \rho_0^n + \sigma \frac{\kappa}{\lambda + \kappa^2} u_0 + \left(1 + \frac{\kappa}{\sigma} + \beta \frac{\kappa^2}{\lambda + \kappa^2}\right) \int_{-\infty}^0 \rho f_\rho(\rho) d\rho. \end{aligned} \tag{8}$$

As long as $\int_{-\infty}^0 \rho f_\rho(\rho) d\rho < 0$, (8) implies that the optimal interest rate is lower than if there was no chance of a binding ZLB tomorrow, *i.e.* if $f_\rho(\rho) = 0$ for $\rho \leq 0$. The interest rate is lower today to offset the deflationary and recessionary effects of the possibility of a binding ZLB tomorrow. If $\rho_0^n < \rho_0^*$, then the ZLB binds today and optimal policy is $i_0 = 0$. In this case

$$x_0 = \frac{\rho_0^n}{\sigma} + \left(1 + \frac{\kappa}{\sigma}\right) E_0 x_1; \quad \pi_0 = \kappa \frac{\rho_0^n}{\sigma} + \left((1 + \beta) \kappa + \frac{\kappa^2}{\sigma}\right) E_0 x_1. \tag{9}$$

Notice from (6) that higher uncertainty makes it more likely that the ZLB will bind at $t = 0$. Specifically, even if agents were certain that the ZLB would not bind at $t = 1$, $E_0 x_1 = E_0 \pi_1 = 0$ and $i_0 = 0$ if $\rho_0^n \leq -\sigma \kappa u_0 / (\lambda + \kappa^2)$. So the possibility of the ZLB binding tomorrow increases the chances of being constrained by the ZLB today.

Since $E_0 x_1$ is a sufficient statistic for $\int_{-\infty}^0 \rho f_\rho(\rho) d\rho$ in (8), the optimal policy has the flavor of a traditional forward-looking policy reaction function that only depends on the conditional expectations of output and inflation gaps. However $E_0 x_1$ is not independent of a mean preserving spread or any other change in the distribution of ρ_1^n. Accordingly, optimal policy here departs from the certainty equivalence principle which says that the

10

extent of uncertainty *in the underlying fundamentals* (in our case ρ_1^n) does not affect the optimal interest rate.[13] Furthermore, as a practical matter the central bank must infer private agents' $E_0 x_1$ in order to determine optimal policy. Since $E_0 x_1$ depends on the entire distribution of ρ_1^n, so must the central bank's estimates of it, which is a much more difficult inference problem than in the certainty equivalence case.

Turning specifically to the issue of uncertainty, we obtain the following unambiguous comparative static result:

Proposition 1 *Higher uncertainty,* i.e. *a mean-preserving spread, in the distribution of the natural rate ρ_1^n tomorrow leads to a looser policy today.*

To see this, rewrite the key quantity $\int_{-\infty}^{0} \rho f_\rho(\rho) d\rho = E \min(\rho, 0)$. Since the min function is concave, higher uncertainty through a mean-preserving spread about ρ_1^n leads to lower, *i.e.* more negative, $E_0 x_1$ and $E_0 \pi_1$, and hence lower i_0.[14]

The effect of higher uncertainty on i_0 is unambiguous, but the effect on the output gap and inflation is more subtle. If the ZLB does not bind at $t = 0$ initially, higher uncertainty leads to lower $E_0 \pi_1$ and $E_0 x_1$ and consequently higher x_0 and lower π_0 according to equation (7). On the other hand, if the ZLB does bind at $t = 0$ initially, then higher uncertainty leads to lower x_0 and π_0 according to equation (9).[15] Hence, overall the effect of higher uncertainty on π_0 is unambiguously negative, but the effect on x_0 may be positive or negative.

Another interesting feature of the solution is that the distribution of the positive values of ρ_1^n is irrelevant for policy. That is, policy today is adjusted only with respect to the states of the world in which the ZLB might bind tomorrow. The logic is that if a very high value of ρ_1^n is realized, monetary policy can adjust to it and prevent a bout of inflation. This is a consequence of the standard principle that, outside the ZLB, natural rate shocks can and should be perfectly offset by monetary policy.

---

[13]Recent statements of the certainty equivalence principle in models with forward-looking variables can be found in Svensson and Woodford (2002, 2003).

[14]See Mas-Colell, Whinston, and Green (1995, Proposition 6.D.2, pp. 199) for the relevant result regarding the effect of a mean preserving spread on the expected value of concave functions of a random variable.

[15]Finally, there is a case where the ZLB does not bind initially, but it binds if uncertainty is higher. In this case, x_0 may be lower or smaller with higher uncertainty, while π_0 is always smaller.

2.1.3 Discussion

Proposition 1 has several predecessors; perhaps the closest are Adam and Billi (2007), Nakata (2013a,b) and Nakov (2008) who demonstrate numerically how, in a stochastic environment, the ZLB leads the central bank to adopt a looser policy. Our contribution is to provide a simple analytical example.[16] This result has been correctly interpreted to mean that if negative shocks to the natural rate lead the economy to be close to the ZLB, the optimal response is to lower the interest rate aggressively to reduce the likelihood that the ZLB becomes binding. The same logic applies to liftoff. Following an episode where the ZLB has been a binding constraint, the central bank should not raise rates as if it were sure the ZLB constraint would never bind again.[17] Even though the best forecast may be that the economy will recover and exit the ZLB – *i.e.* in the context of the model, that $E_0(\rho_1^n) > 0$ – it can be optimal to have zero interest rates today. Note that policy is looser when the probability of being constrained by the ZLB in the future is high or the potential severity of the ZLB problem is large, *i.e.* $\int_{-\infty}^0 \rho f_\rho(\rho) d\rho$ is a large negative number; the economy is less sensitive to interest rates (high σ), and the Phillips curve is steep (high κ).

With higher uncertainty, the increase in interest rates on average will be faster from $t = 0$ to $t = 2$. This follows since the $t = 2$ interest rate is unaffected by uncertainty while at $t = 0$ it is lower. More generally, when uncertainty about being constrained by the ZLB in the future dissipates, the interest rate can rise quickly because the effects holding it down disappear along with the uncertainty.

While we have deliberately focused on a very simple example, our results hold under more general conditions. For instance, the same results still hold if $\{\rho_t^n\}_{t \geq 2}$ follows an arbitrary stochastic process as long as it is positive. In the appendix we consider the case of optimal policy with uncertainty about cost-push inflation. We show that optimal policy also is looser if there is a chance of a binding ZLB in the future due to a low cost-push shock. Furthermore,

---

[16]See also Nakata and Schmidt (2014) for a related analytical result in a model with two-state Markov shocks.

[17]Indeed, private sector forecasters attribute a significant likelihood of a return to the ZLB: respondents to the January 2015 Federal Reserve Bank of New York survey of Primary Dealers put the odds of returning to the ZLB within two years following liftoff at 20%.

the risk that inflation picks up due to a high cost-push shock does not affect policy today. If such a shock were to occur tomorrow, it will lead to some inflation; however, there is nothing that policy *today* can do about it. Finally, while the model chosen is highly stylized, the core insights would likely continue to hold in a medium-scale model with a variety of shocks and frictions.

Intuitively, we expect a version of Proposition 1 to still hold with commitment as well. Optimal policy with commitment involves promising at $t = 0$ that should the ZLB bind at $t = 1$, the central bank will keep interest rates lower for $t \geq 2$ than it would otherwise. As is well known, this policy reduces the size of the inflation and output gaps at $t = 1$, but it does not eliminate them entirely. These gaps then could generate negative expected inflation and output gaps at $t = 0$ that become more negative the larger the $t = 1$ uncertainty. So higher uncertainty should lead to looser policy at $t = 0$ just as in the case of discretion.

One obvious limitation to these results is that we have assumed (and will continue do so when studying the backward-looking model below) that there is no cost to raising rates quickly if needed. For example, our welfare criterion does not value interest rate smoothing. Smoothing has been rationalized by Goodfriend (1991) and others as facilitating financial market adjustments or as a signaling tool. It is true also that estimated reaction functions include lagged funds rate terms to fit historical data. Nonetheless there have been instances when the FOMC has moved quickly. Some of these occurred as recessions unfolded, but not all: between February 1994 and February 1995 rates were tightened by 300 basis points (bps) and between November 1988 and February 1989 by nearly 165 bps. Moreover, as Sack (2000) and Rudebusch (2002)) argue, interest rate smoothing might reflect learning about an uncertain economy rather than a desire to avoid large changes in interest rates *per se*. The policy prescriptions derived from our models are specifically aimed at addressing such uncertainty.

2.2 The buffer stock channel

The buffer stock channel does not rely on forward-looking behavior, but rather on the view that the economy has some inherent *momentum, e.g.* due to adaptive inflation expectations, inflation indexation, habit persistence, adjustment costs or hysteresis. Suppose that output or inflation have a tendency to persist. If there is a risk that the ZLB binds tomorrow, building up output and inflation today creates some buffer against hitting the ZLB tomorrow.

This intuition does not guarantee that it is optimal to increase output or inflation today. In particular, the benefit of higher inflation or output today in the event that a ZLB event arises tomorrow must be weighed against the costs of excess output and inflation today, as well as tomorrow's cost to bring down the output gap or inflation if the ZLB turns out not to bind. So it is important to verify that our intuition holds up in a model.

To isolate the buffer stock channel from the expectations channel we focus on a purely backward-looking "Old" Keynesian model. Purely backward-looking models do not have micro-foundations like the New Keynesian model does, but backward-looking elements appear to be important empirically.[18] Backward-looking models have been studied extensively in the literature, including by Laubach and Williams (2003), Orphanides and Williams (2002), Reifschneider and Williams (2000) and Rudebusch and Svensson (1999).

The model we study simply replaces the forward-looking terms in (1) and (2) with backward-looking terms:

$$\pi_t = \xi \pi_{t-1} + \kappa x_t + u_t; \tag{10}$$

$$x_t = \delta x_{t-1} - \frac{1}{\sigma} \left(i_t - \rho_t^n - \pi_{t-1} \right), \tag{11}$$

where $0 < \xi < 1$ and $0 < \delta < 1$. This model is essentially the same as the simple example Reifschneider and Williams (2000) use to motivate their analysis of monetary policy con-

---

[18]Indeed empirical studies based on medium-scale DSGE models, such as those considered by Christiano et al. (2005) and Smets and Wouters (2007), find backward-looking elements are essential to account for the empirical dynamics. Backward-looking terms are important in single-equation estimation as well. See for example Fuhrer (2000), Gali and Gertler (1999) and Eichenbaum and Fisher (2007).

strained by the ZLB. Unlike in the New Keynesian model it is difficult to map ρ_t^n directly to underlying fundamental shocks as we do in equation (3). For simplicity we continue to refer to this exogenous variable as the natural rate and use (3) as a guide to interpreting it, but it is perhaps better to think of it as simply a "demand" shock or "IS" shock.

2.2.1 Analysis

We consider the ZLB scenario described in Section 2.1.1 and again solve the model backwards from $t = 2$ to determine optimal policy at $t = 0$ and how this is affected by uncertainty in the natural rate at $t = 1$. After $t = 1$ the economy does not experience any more shocks, but it inherits initial lagged inflation and output terms π_1 and x_1, which may be positive or negative. The output gap term can be easily adjusted by changing the interest rate i_t, provided the central bank is not constrained by the ZLB at $t = 2$, $i.e.$ if $\rho_2^n = \bar{\rho}$ is large enough, an assumption we will maintain.[19] Given the quadratic loss, it is optimal to smooth this adjustment over time, so the economy will converge back to its steady-state slowly. The details of this adjustment after $t = 2$ are not very important for our analysis. What is important is that the overall loss of starting from $t = 2$ with lagged inflation π_1 and output gap x_1 is a quadratic function of π_1 only; we can write it as $W\pi_1^2/2$, where W is a constant that depends on λ, κ, ξ and β and is calculated in the appendix.

Turn now to optimal policy at $t = 1$. Take the realization of ρ_1^n and last period's output gap x_0 and inflation π_0 as given. Substituting for π_1 and i_1 using (10) and (11), and taking into account the ZLB constraint, optimal policy at $t = 1$ solves the following problem:

$$V(x_0, \pi_0, \rho_1^n) = \min_{x_1} \frac{1}{2} \left((\xi\pi_0 + \kappa x_1)^2 + \lambda x_1^2 \right) + \beta \frac{W}{2}\pi_1^2 \text{ s.t. } x_1 \leq \delta x_0 + \frac{\pi_0 + \rho_1^n}{\sigma}.$$

where the policymaker now anticipates the cost of having inflation π_1 tomorrow, and her choices are affected by yesterday's values x_0 and π_0.

---

[19]Relaxing it would only strengthen our results.

Depending on the value of ρ_1^n, two cases can arise. Define the threshold value:

$$\rho_1^*(x_0, \pi_0) = -\left(\frac{(1+\beta W)\kappa\xi}{(1+\beta W)\kappa^2 + \lambda}\sigma + 1\right)\pi_0 - \sigma\delta x_0. \tag{12}$$

For $\rho_1^n \geq \rho_1^*(x_0, \pi_0)$ the ZLB is not binding, otherwise it is. Hence the probability of hitting the ZLB is $\int_{-\infty}^{\rho_1^*(x_0, \pi_0)} f_\rho(\rho)d\rho$. In contrast to the forward-looking case, the probability of being constrained by the ZLB constraint is now endogenous at $t = 1$ and can be influenced by policy at $t = 0$. As indicated by (12), a higher output gap or inflation at $t = 0$ will reduce the likelihood of hitting the ZLB at $t = 1$.

If $\rho_1^n \geq \rho_1^*(x_0, \pi_0)$ optimal policy at $t = 1$ yields

$$x_1 = -\frac{(1+\beta W)\kappa\xi}{(1+\beta W)\kappa^2 + \lambda}\pi_0; \quad \pi_1 = \frac{\lambda\xi}{(1+\beta W)\kappa^2 + \lambda}\pi_0.$$

This is similar to the forward-looking model's solution that reflects the trade-off between output and inflation, except that optimal policy now takes into account the cost of having inflation away from target tomorrow, through W. The loss for this case is $V(x_0, \pi_0, \rho_1^n) = W\pi_0^2/2$ since in this case the problem is the same as the one faced at $t = 2$. If $\rho_1^n < \rho_1^*(x_0, \pi_0)$ the ZLB binds, in which case

$$x_1 = \delta x_0 + \frac{\pi_0 + \rho_1^n}{\sigma}; \quad \pi_1 = \kappa\delta x_0 + \pi_0\left(\xi + \frac{\kappa}{\sigma}\right) + \kappa\frac{\rho_1^n}{\sigma}.$$

The expected loss from $t = 1$ on as a function of the output gap and inflation at $t = 0$ is then given by:

$$
\begin{aligned}
L(x_0, \pi_0) &= \frac{W}{2}\pi_0^2 \int_{\rho_1^*(x_0, \pi_0)}^{+\infty} f_\rho(\rho)d\rho + \\
&\int_{-\infty}^{\rho_1^*(x_0, \pi_0)} \frac{1+\beta W}{2}\left(\kappa\delta x_0 + \pi_0\left(\xi + \frac{\kappa}{\sigma}\right) + \kappa\frac{\rho}{\sigma}\right)^2 + \frac{\lambda}{2}\left(\delta x_0 + \frac{\pi_0 + \rho}{\sigma}\right)^2 f_\rho(\rho)d\rho.
\end{aligned}
$$

This expression reveals that the initial conditions x_0 and π_0 matter by shifting the payoff from continuation in the non-ZLB states, $W\pi_0^2/2$; the payoff in the case where the ZLB

binds (the second integral); and the relative likelihood of ZLB and non-ZLB states through $\rho_1^*(x_0, \pi_0)$. Since the loss function is continuous in ρ (even at $\rho_1^*(x_0, \pi_0)$), this last effect is irrelevant for welfare at the margin.

The last step is to find the optimal policy at time 0, taking into account the effect on the expected loss tomorrow:

$$\min_{x_0} \frac{1}{2} \left((\xi \pi_{-1} + \kappa x_0 + u_0)^2 + \lambda x_0^2 \right) + \beta L(x_0, \pi_0) \text{ s.t. } x_0 \leq \delta x_{-1} + \frac{\rho_0^n + \pi_{-1}}{\sigma}.$$

We use this expression to prove the following, which is analogous to Proposition 1:

Proposition 2 *For any initial condition, a mean-preserving spread in the distribution of the natural rate ρ_1^n tomorrow, leads to a looser optimal policy today.*

From (10) and (11), higher uncertainty also leads to larger x_0 and π_0. The proof of Proposition 2 is in the appendix. Note that it incorporates the case of uncertainty regarding cost-push shocks at $t = 1$ and shows that a mean preserving spread in the cost-push shock tomorrow leads to looser policy today as well.

Our model also implies that an increase in uncertainty over the initial output gap will lead to looser policy. Specifically we have:

Proposition 3 *Suppose the initial output gap x_{-1} is unknown at $t = 0$ but becomes known at $t = 1$ and the central bank has a priori distribution over x_{-1}. Then a mean-preserving spread in this prior distribution leads optimal policy to be looser at $t = 0$.*

The proof of this proposition is similar to the one for Proposition 2. This result is particularly germane to the current policy environment where there is uncertainty over the amount of slack in the economy. Therefore Proposition 3 provides an additional rationale for delaying liftoff.

2.2.2 Discussion

As far as we know Proposition 2 is a new result, but its implications are similar to those of Proposition 1. As in the forward-looking case, liftoff from an optimal zero interest rate should be delayed today with an increase in uncertainty about the natural rate or cost-push shock that raises the odds of the ZLB binding tomorrow. Similarly, even if not constrained by the ZLB today, an increase in uncertainty about the likelihood of being constrained by the ZLB tomorrow leads to a reduction in the policy rate today. So the buffer stock channel and the expectations channel have very similar policy implications but for very different reasons. The expectations channel involves the possibility of being constrained by the ZLB tomorrow feeding backward to looser policy today. The buffer stock channel has looser policy today feeding forward to reduce the likelihood and severity of being at the ZLB tomorrow. Note that as in the forward-looking model optimal policy prescribes that interest rates rise as the likelihood of being constrained by the ZLB in the future falls, even if the output gap or inflation do not change.

It is useful to compare the policy implications of the buffer stock channel to the argument developed in Coibion, Gorodnichenko, and Wieland (2012). That paper studies the tradeoff between the level of the inflation target and the risk of hitting the ZLB using policy reaction functions instead of optimal policy.[20] Our analysis does not require a drastic change in monetary policy in order to improve outcomes. It is achieved via standard interest rate policy rather than a credibility-damaging change to the inflation target.

2.3 Quantitative assessment

We now assess the quantitative significance of the expectations and buffer stock channels using calibrated versions of the forward- and backward-looking models that we solve numerically. With parameters drawn from the literature and initial conditions calibrated to early 2015, we compare equilibrium outcomes under optimal discretion to alternative policies that

---

[20]Another difference is that they study a medium-scale DSGE model with both forward- and backward-looking elements; because of this added complexity they use a different solution method.

do not take into account uncertainty. Our numerical methods are described in the appendix. Importantly, and in contrast to most of the literature, they allow for uncertainty to affect policy and to be reflected in welfare.

2.3.1 Parameter values

The parameter values are reported in Table 1. We use the same values for parameters that are common to both models. The time period is one quarter, with $t = 1$ taken to be 2015q1. The natural rate ρ_t^n is the sum of deterministic and random components. We assume the deterministic component rises linearly between $t = 1$ and $t = T > 1$, after which it remains constant at $\overline{\rho} = 1.75\%$, which corresponds to the median long run funds rate in the March 2015 FOMC Summary of Economic Projections, less the FOMC's inflation target $\pi^* = 2$. The random component is AR(1) with auto-correlation coefficient ρ_ε and innovation standard deviation σ_ε. We also assume there is an i.i.d. cost-push shock with standard deviation σ_u. There is no uncertainty for $t > T$.

Obviously the degree of uncertainty we assume is central to our findings. The particular values of ρ_ε and σ_ε are not as important to our results as the unconditional volatility they imply. There is wide variation in estimates of volatility in the natural rate, corresponding to differences in theoretical concepts, models and empirical methods used. Our calibration implies the unconditional standard deviation of the natural rate is 2.5% at an annual rate. This lies within the range of estimates in Barsky et al. (2014), Cúrdia, Ferrero, Ging Cee Ng, and Tambalotti (2015) and Laubach and Williams (2003). The auto-correlation coefficient is set midway between the values in Adam and Billi (2007) and Cúrdia et al. (2015). We set the standard deviation of the cost-push shock σ_u close to the value used in Adam and Billi (2007). Assuming serial correlation or a moderately different unconditional standard deviation of the cost-push shock is not very important for our results. Finally, by assuming the economy is not subject to shocks for $t > T$ and that the long run natural rate $\overline{\rho}$ is a known constant we have been conservative in our specification of uncertainty.

The Phillips curve slope, elasticity of inter-temporal substitution and the discount factor

Table 1: Parameter values

Parameter	Description	Value
β	Discount factor	0.995
κ	Slope of Phillips Curve	0.025
σ	Inverse elasticity of substitution	2
σ_ε	Std. dev. natural rate innovation	1.32
σ_u	Std. dev. of cost-push innovation	0.10
ρ_ε	Serial correlation of natural rate	0.85
ρ_u	Serial correlation of cost-push	0
λ	Weight on output stabilization	0.25
π^*	Steady-state inflation (annualized)	2
ρ_1^n	Value of natural rate at time 1	-0.5
T	Quarters to reach terminal natural rate	24
$\overline{\rho}$	Terminal natural rate (annualized)	1.75
δ	Backward-looking IS curve coef.	0.75
ξ	Backward-looking Phillips curve coef.	0.95
x_0	Initial condition for the output gap	-1.5
π_0	Initial condition for inflation	1.3
ϕ	Taylor rule coefficient on inflation	1.5
γ	Taylor rule coefficient on output gap	0.5

Note: Values of standard deviations, inflation, the output gap, and the natural rate are shown in percentage points.

are all set to values common in the New Keynesian literature. For the backward-looking model we set the coefficient on lagged inflation in (10) to $\xi = 0.95$, reflecting the fact that inflation has been very persistent in recent years.[21] The coefficient on lagged output in (11) is $\delta = 0.75$, in order to generate significant persistence in the output gap. For the backward-looking model we assume an initial inflation rate of 1.3%, a recent reading for core PCE inflation, and an initial output gap $x_0 = -1.5\%$, based on a simple calculation using the 2014q4 unemployment rate (5.7%), an estimate of the natural rate of unemployment (5.0%) and Okun's law. As indicated by Proposition 3, adding uncertainty about the initial output gap would only strengthen our results.[22]

---

[21] Note that it is not clear how to map estimates of the lagged inflation coefficient in the literature to our backward-looking model since these are based on Phillips curves with forward looking terms.

[22] In the appendix we discuss the implications for our results of different values for the initial gaps, uncertainty, ρ_0^n, δ and ξ.

We measure the quantitative effect of uncertainty on policy by comparing equilibrium outcomes under optimal discretion to a scenario in which we solve for optimal discretion when the central bank observes the current natural rate and cost-push shocks but acts as if there will be no more shocks. Private agents understand this policy but take into account the true nature of uncertainty. Actual outcomes will be inconsistent with the central bank's assumptions so we call this the "naive" policy. We also compare equilibrium outcomes under optimal discretion to those obtained assuming the central bank follows a reaction function with weights on inflation and the output gap as in Taylor (1993), and a constant term equal to 3.75% corresponding to $\overline{\rho} + \pi^*$.

2.3.2 Results for the forward-looking model

Figure 1 displays representative paths of the nominal interest rate, inflation and the output gap under optimal discretion (red), the naive policy (green) and the Taylor rule (blue), calculated by setting the *ex post* realized shocks to zero, the modal outcome. Under the modal outcome the interest rate under the naive policy follows the natural rate exactly. The difference between the green and red interest rate paths indicates the substantial impact uncertainty has on optimal policy; the naive policy is between 50 and 150 bps above the optimal policy for 2 years. This difference in policy has little impact on the output gap, but under optimal policy the inflation gap is closed much faster. The inflation gap is more negative under the naive policy because the interest rate is higher both initially and in the future since it does not take into account uncertainty about the ZLB.[23] The Taylor rule prescribes rates above both the optimal and naive policies for most of the simulation period and because agents are forward looking this feeds backward to cause much more negative gaps.[24]

Table 2 summarizes the distribution of outcomes under the three different policies based

---

[23]One might be surprised that inflation is far below target under the naive policy even though the output gap is near target. This reflects that we plotted the modal outcome, rather than the mean, and that the distribution of inflation and output gap outcomes are skewed to the left.

[24]For some calibrations the outcomes under the Taylor rule can be so bad that liftoff is delayed and rates are below the optimal policy throughout the simulation period.

Figure 1: Liftoff in the forward-looking model
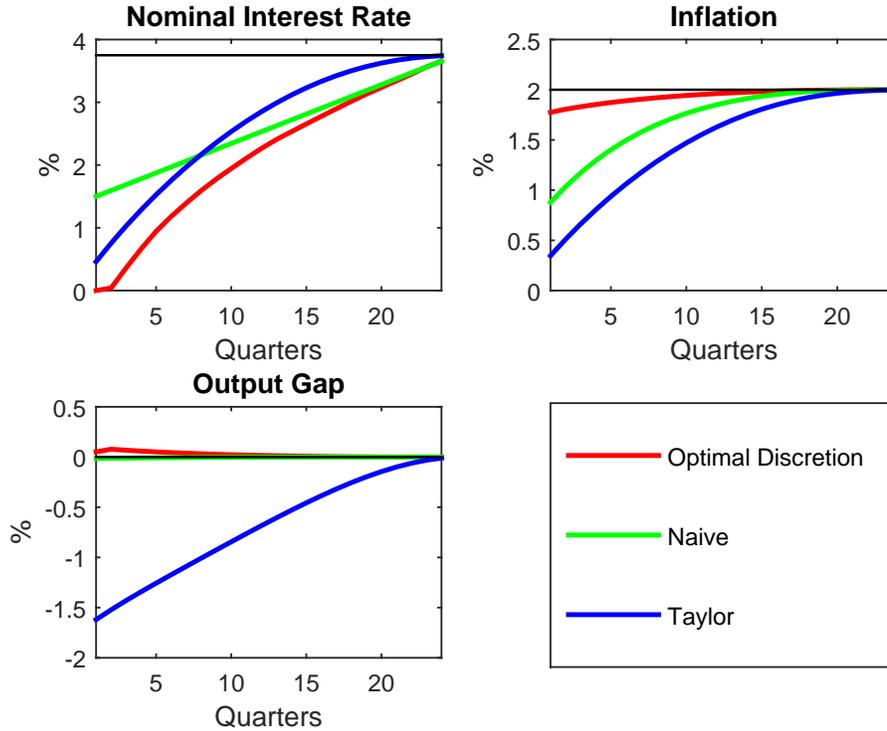
on simulating 50,000 paths drawn from the calibrated distributions of the shocks. Optimal discretion implies 1/3 the expected loss of the naive policy and 1/8 the loss of the Taylor rule.[25] One way to interpret these losses is to calculate the per period reduction in the output and inflation gaps that would make the central banker indifferent between the outcomes under the optimal policy and those under the alternatives. Both gaps would have to be 43% and 65% smaller under the naive policy and the Taylor rule, respectively, to achieve this indifference. The median liftoff (defined as the nominal interest rate exceeding 25 bps) under optimal discretion is delayed by 2 quarters compared to the other policies; the mean liftoff is delayed by more than 3 quarters reflecting skewness in the outcomes. At the time of liftoff inflation and output are much closer to target under optimal discretion compared to the two alternative policies.

When comparing policies it is also important to assess how well each balances the risks

---

[25]The sub-optimality of the Taylor rule does not hold by definition because it provides commitment which may lead to more favorable outcomes.

Table 2: Forward-looking simulation

Statistic	Optimal Discretion	Naive	Taylor Rule
Expected loss	0.02	0.06	0.16
Mean time at liftoff	4.11	1.00	1.00
Median time at liftoff	3	1	1
Median π at liftoff	1.81	0.88	0.35
Median x at liftoff	0.08	-1.44	-1.62
75th percentile max(π)	2.69	2.42	2.17
25th percentile min(x)	-0.72	-1.44	-2.63
Median standard deviation Δi	1.87	1.88	0.97

of bad outcomes. We do this by comparing the 75th percentile across simulations of the maximum inflation gap and the 25th percentile of the lowest output gap over the first 6 years. Under optimal policy the bad output outcomes are much lower than under either alternative policies. The bad inflation outcomes do not seem particularly high under any of the policies.

The statistic in the bottom row is the median standard deviation of changes in the nominal interest rate. By comparing interest rate volatility under the Taylor rule in our model with that implied by the same Taylor rule in the data we can determine whether the uncertainty underlying our results is reasonable. If the volatility were much higher in our simulations we would conclude that it is unreasonably large. In fact, the 0.97 standard deviation in our Taylor rule simulations is only a little larger than the 0.88 standard deviation we find in our data.[26] Interest rates are more volatile under both the optimal and naive policies because they respond to all fundamental shocks rather than just inflation and output.[27]

2.3.3 Results for the backward-looking model

Figure 2 is the analogue of Figure 1 for the backward-looking model. Obviously, the dynamics of return to target are quite different from the forward-looking model, but the key qualitative results are the same. As in the forward-looking model, optimal policy is substantially looser

---

[26]The appendix describes how we calculate the interest rate implied by the Taylor rule with our data.
[27]We thank Johannes Wieland for suggesting that we assess the volatility of the nominal interest rate.

than both the naive policy and the Taylor rule. Here the optimal policy prescribes much more delay in lifting off from the ZLB. Delay now occurs under the naive policy because it is optimal to stimulate output strongly in order to return inflation to target, but this delay is less than under the optimal policy. The optimal policy also has a sharper liftoff than the naive policy. However the increases under optimal policy are equivalent to just 25 bps a meeting, the same as the "measured pace" during the Fed tightening over 2004–2006. Qualitatively the differences in the output and inflation outcomes across the three policies are similar to the forward-looking model as well. Taking into account uncertainty about the ZLB leads the optimal policy to return inflation to target faster than the naive policy and it achieves this by allowing the output gap to overshoot more to build a buffer against the possibility of bad shocks in the future.

Figure 2: Liftoff in the backward-looking model
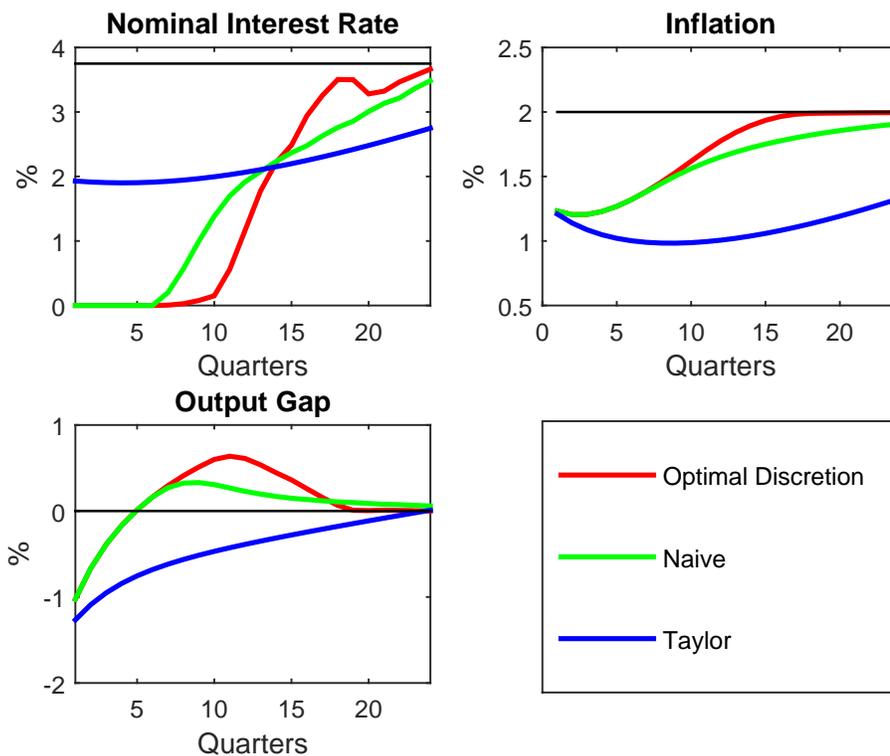
Table 3 is constructed analogously to Table 2. It shows that optimal policy provides only a marginal improvement over the naive policy in terms of expected losses, due to the

offsetting effects of the inflation and output gaps. The median gaps are roughly closed at liftoff under both the optimal and naive policies, but they are quite large under the Taylor rule. The bad outcomes are similar across the three scenarios. Finally, note that the volatility of the interest rate under the Taylor rule is lower here compared to the data and the forward-looking model so the underlying uncertainty is not excessive.

Table 3: Backward-looking simulation

Statistic	Optimal Discretion	Naive	Taylor Rule
Expected loss	0.27	0.28	0.60
Mean time at liftoff	12.5	10.3	1.00
Median time at liftoff	10	7	1
Median π at liftoff	2.00	1.81	1.21
Median x at liftoff	0.32	0.00	-1.27
75th percentile max(π)	3.02	2.83	2.81
25th percentile min(x)	-1.65	-1.70	-1.54
Median standard deviation Δi	2.96	3.10	0.54

Figure 3: Large cost-push shock in the backward-looking model
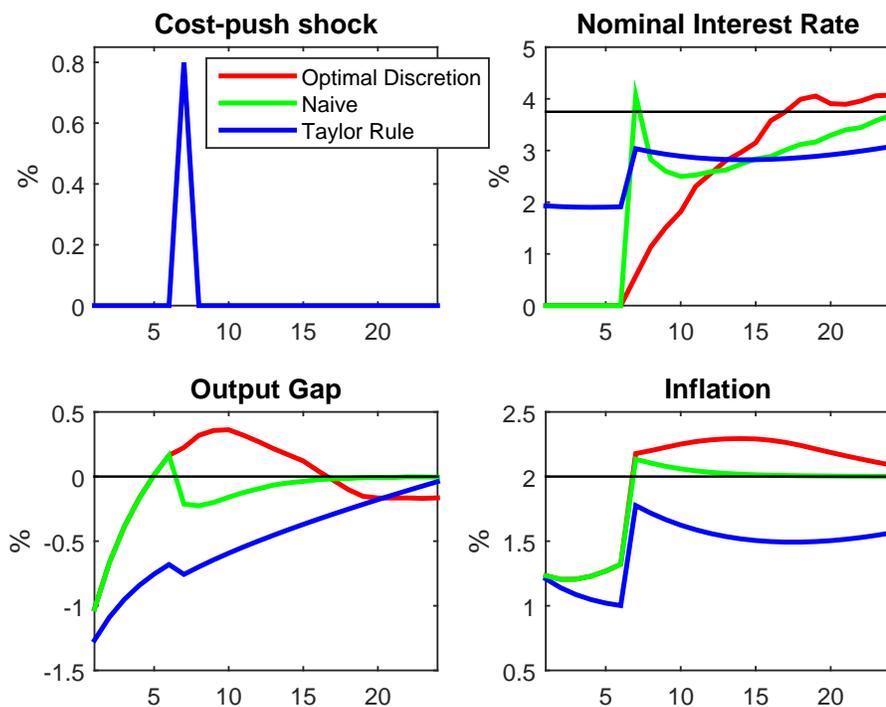
We conclude by illustrating one of the risks the optimal policy is able to address, namely the possibility that a shock will drive up inflation before the baseline liftoff. Figure 3 depicts a particular simulation where there is a large positive cost-push shock before the liftoff under the optimal policy shown in Figure 2. The shocks trigger earlier liftoff under the optimal policy so that the inflation response is mild. The implication is that staying at zero longer under the optimal policy does not impair the ability of the central bank to respond to future contingencies. However, it does have to be prepared to raise rates promptly. We obtain similar results with the forward looking model.

3 Historical precedents for risk management

The previous section demonstrates that the ZLB justifies a risk management approach to monetary policy. One may question whether following such an approach would be a departure from past FOMC behavior. Clearly, concerns about the ZLB are a relatively recent phenomenon. Nevertheless there are many reasons why a risk management approach can be justified when away from the ZLB and we begin this section by reviewing these rationales. We then demonstrate that the Federal Reserve has used risk management to justify its policy decisions over the period 1987-2008.

The FOMC minutes and other Federal Reserve communications reveal a number of episodes when *uncertainty* or *insurance* were used to justify its policy decisions. Sometimes the FOMC indicated that it took a wait-and-see approach to taking further actions or muted a funds rate move due to its uncertainty over the course of the economy or the extent to which early policy moves had yet shown through to economic activity and inflation. At other times the Committee said its policy stance was taken in part as insurance against undesirable outcomes; during these times, the FOMC often noted that the potential costs of a policy overreaction likely were modest compared to the scenario it was insuring against.

Two episodes are particularly revealing. The first is the hesitancy of the Committee to raise rates in 1997 and 1998 to counter inflationary threats because of uncertainty generated by the Asian financial crisis and the subsequent rate cuts following the Russian default.

The second is the loosening of policy over 2000 and 2001, when uncertainty over the degree to which growth was slowing and the desire to insure against downside risks appeared to influence policy. Furthermore, later in the period, the Committee's aggressive actions also seemed to be influenced by attention to the risks associated with the ZLB on interest rates.

While the historical record is replete with references that suggest uncertainty or insurance motives influenced the stance of policy, it is unclear at this stage whether risk management had a material impact on policy. Therefore we conclude this section by quantifying these references into variables that we use in Section 4 to assess the importance of risk management for actual policy decisions.

3.1 Rationales for risk management away from the ZLB

Policymakers have long-emphasized the importance of uncertainty in their decision- making. As Greenspan (2004) put it: "(t)he Federal Reserve's experiences over the past two decades make it clear that uncertainty is not just a pervasive feature of the monetary policy landscape; it is the defining characteristic of that landscape." This sentiment seems at odds with linear-quadratic models in which optimal policy involves adjusting the interest rate in response to only the mean of the distribution of shocks away from the ZLB. What kinds of factors cause departures from such conditions and justify the risk management approach?

Relaxing the assumption of a quadratic loss function is perhaps the simplest way to generate a rationale for risk management. The quadratic loss function is justified by Woodford (2003) as being a local approximation to consumer welfare. However, it might not be a good approximation when large shocks drive the economy far from the underlying trend; alternatively it might simply be an inadequate approximation of FOMC behavior. Examples of models with asymmetric loss functions include Surico (2007), Kilian and Manganelli (2008), and Dolado, María-Dolores, and Ruge-Murcia (2004). The latter paper shows the optimal policy rule can involve nonlinear output gap and inflation terms if policymakers are less averse to output running above potential than below it. The relevance of higher moments in the distribution of shocks for optimal policy is an obvious by-product of these nonlinearities.

Nonlinearities in economic dynamics are another natural motivation. For example, suppose recessions are episodes when self-reinforcing dynamics amplify the effects of downside shocks. This could be modeled as a dependence of current output on lagged output, as in our backward-looking model, but this dependence is concave rather than linear. Intuitively, negative shocks have a more dramatic effect on reducing future output than positive shocks have on increasing it, and so greater uncertainty leads to looser optimal policy to guard against the more detrimental outcomes. Alternatively, suppose the Phillips curve is convex, perhaps owing to downward nominal wage rigidities that become more germane with low inflation. Here, a positive shock to the output gap leads to a significant increase of inflation above target while a negative shock leads to a much smaller decline in inflation. The larger the spread of these shocks, the greater the odds of experiencing a bad inflation outcome. Optimal policy guards against this, leading to a tightening bias.[28]

The risk management approach also appears in the large literature on how optimal monetary policy should adjust for uncertainty about the true model of the economy. Brainard (1967) derived the important result that uncertainty over the effects of policy should lead to caution and smaller policy responses to deviations from target. In contrast, the robust control analysis of Hansen and Sargent (2008) has been interpreted to mean that uncertainty over model miss-specification should generate aggressive policy actions. As explained by Barlevy (2011), both the attenuation and aggressiveness results depend on the specifics of the underlying environment. Nonetheless, these analyses still often indicate that higher moments of the distribution of shocks can influence the setting of optimal policy.

3.2   1997–1998

The year 1997 was a good one for the U.S. economy: real GDP increased 3-3/4 percent (the March 1998 third estimate), the unemployment rate fell to 4.7 percent and core CPI inflation was 2-1/4 percent. With solid growth and tight labor markets, the FOMC clearly was concerned about a buildup in inflationary pressures. As noted in the Federal Reserve's

---

[28]The fact that a convex Phillips curve can lead to a role for risk management has been discussed by Laxton, Rose, and Tambakis (1999) and Dolado, María-Dolores, and Naveira (2005).

February 1998 Monetary Policy Report:

> The circumstances that prevailed through most of 1997 required that the Federal
> Reserve remain especially attentive to the risk of a pickup in inflation. Labor
> markets were already tight when the year began, and nominal wages had started
> to rise faster than previously. Persistent strength in demand over the year led to
> economic growth in excess of the expansion of the economy's potential, intensi-
> fying the pressures on labor supplies.

Indeed, over much of the period between early 1997 and mid-1998, the FOMC directive
maintained a bias indicating that it was more likely to raise rates to battle inflationary
pressures than it was to lower them. Nonetheless, the FOMC left the funds rate unchanged
at 5.5 percent from March 1997 until September 1998. Why did it do so?

Certainly the inaction in large part reflected the forecast for growth to moderate to a more
sustainable pace as well as the fact that actual inflation had remained contained despite tight
labor market conditions. Based on the funds rate remaining at 5.5 percent, the August 1998
Greenbook projected GDP growth to slow from 2.9 percent in 1998 to 1.7 percent in 1999.
The unemployment rate was projected to rise to 5.1 percent by the end of 1999 and core CPI
inflation was projected to edge down to 2.1 percent. But, in addition, on several occasions
heightened uncertainty over the outlook for growth and inflation apparently reinforced the
decision to refrain from raising rates. The following quote from the July FOMC 1997 minutes
is a revealing example:

> While the members assessed risks surrounding such a forecast as decidedly tilted
> to the upside, the slowing of the expansion should keep resource utilization from
> rising substantially further, and this outlook together with the absence of sig-
> nificant early signs of rising inflationary pressures suggested the desirability of
> a cautious "wait and see" policy stance at this point. In the current uncertain
> environment, this would afford the Committee an opportunity to gauge the mo-
> mentum of the expansion and the related degree of pressure on resources and
> prices.

Furthermore, the Committee did not see high costs to "waiting and seeing." They thought any increase in inflation would be slow, and that if needed a limited tightening would be sufficient to reign in any emerging price pressures. This is seen in the following quote from the same meeting:

> The risks of waiting appeared to be limited, given that the evidence at hand did not point to a step-up in inflation despite low unemployment and that the current stance of monetary policy did not seem to be overly accommodative . . . In these circumstances, any tendency for price pressures to mount was likely to emerge only gradually and to be reversible through a relatively limited policy adjustment.

Thus, it appears that uncertainty and associated risk management considerations supported the Committee's decision to leave policy on hold.

Of course, the potential fallout of the Asian financial crisis on the U.S. economy was a major factor underlying the uncertainty about the outlook. The baseline scenario was that the associated weakening in demand from abroad and a stronger dollar would be enough to keep inflationary pressures in check but would not be strong enough to cause inflation or employment to fall too low. As Chairman Greenspan noted in his February 1998 Humphrey-Hawkins testimony to Congress, there were substantial risks to this outlook, with the delicate balance dictating unchanged policy:

> However, we cannot rule out two other, more worrisome possibilities. On the one hand, should the momentum to domestic spending not be offset significantly by Asian or other developments, the U.S. economy would be on a track along which spending could press too strongly against available resources to be consistent with contained inflation. On the other, we also need to be alert to the possibility that the forces from Asia might damp activity and prices by more than is desirable by exerting a particularly forceful drag on the volume of net exports and the prices of imports. When confronted at the beginning of this month with these, for the moment, finely balanced, though powerful forces, the members of the Federal Open Market Committee decided that monetary policy should most appropriately be kept on hold.

By late in the summer of 1998, this balance had changed, as the strains following the Russian default weakened the outlook for foreign growth and tightened financial conditions in the U.S. The Committee was concerned about the direct implications of these developments on U.S. financial markets, already evident in the data, as well as for the real economy, which were still just a prediction. The staff forecast prepared for the September FOMC meeting reduced the projection for growth in 1999 by about 1/2 percentage point to 1-1/4 percent, predicated on a 75 bp reduction in the funds rate spread out over three quarters. Such a forecast was not a disaster – indeed, at 5.2 percent, the unemployment rate projected for the end of 1999 was still below the staff's estimate of its natural rate. Nonetheless, the FOMC moved much faster than assumed by the staff, lowering rates 25 bps at its September and November meetings as well at an inter-meeting cut in October. According to the FOMC minutes, the rate cuts were made in part as insurance against a worsening of financial conditions and weakening activity. As they noted in September:

> . . . such an action was desirable to cushion the likely adverse consequences on future domestic economic activity of the global financial turmoil that had weakened foreign economies and of the tighter conditions in financial markets in the United States that had resulted in part from that turmoil. At a time of abnormally high volatility and very substantial uncertainty, it was impossible to predict how financial conditions in the United States would evolve . . . In any event, an easing policy action at this point could provide added insurance against the risk of a further worsening in financial conditions and a related curtailment in the availability of credit to many borrowers.

While the references to insurance are clear, the case also can be made that these policy moves were in large part made to realign the misses in the expected paths for growth and inflation from the FOMC's policy goals. At this time the prescriptions to address the risks to their policy goals were in conflict – risks to achieving the inflation mandate called for higher interest rates while risks to achieving the maximum employment mandate called for lower rates. As the above quote from Chairman Greenspan's 1998 testimony indicated, in early 1998 the Committee thought that a 5-1/2 percent funds rate setting kept these risks

in balance. Subsequently, as the odds of economic weakness increased, the Committee cut rates to bring the risks to the two goals back into balance. As Chairman Greenspan said in his February 1999 Humphrey Hawkins testimony:

> To cushion the domestic economy from the impact of the increasing weakness in foreign economies and the less accommodative conditions in U.S. financial markets, the FOMC, beginning in late September, undertook three policy easings . . . These actions were taken to rebalance the risks to the outlook, and, in the event, the markets have recovered appreciably.

So were the late 1998 rate moves a balancing of forecast probabilities, insurance against a downside skew in possible outcomes, or some combination of both? There is no easy answer. This motivates our econometric work in Section 4 that seeks to disentangle the normal response of policy to expected outcomes from uncertainty and other related factors that may have influenced the policy decision.

3.3 2000–2001

In the end, the economy weathered the fallout from the Russian default well. The strength of the economy and underlying inflationary pressures led the FOMC to execute a series of rate hikes that brought the funds rate up to 6.5 percent by May of 2000. At the time of the June 2000 FOMC meeting, the unemployment rate stood at 4.1 percent and core PCE inflation, which the Committee was now using as its main measure of consumer price inflation, was running at about 1-3/4 percent, up from 1-1/2 percent in 1999. The staff forecasted growth would moderate to a rate near or a little below potential but that unemployment would remain near its current level and that inflation would rise to 2.3 percent in 2001 – and this forecast was predicated on another 75 bps tightening. Despite this outlook, the FOMC decided to leave rates unchanged. What drove this pause? It seems likely to us that risk management was an important consideration.

In particular, the FOMC appeared to want to see how uncertainty over the outlook would play out. First, the incoming data and anecdotal reports from Committee members'

business contacts pointed to a slowdown in growth, but the degree of the slowing was not clear. Second, with rates having risen substantially over the past year, and given the lags from policy changes to economic activity, it was unlikely that the full effects of the hikes had yet been felt. Given the relatively high level of the funds rate and the slowdown in growth that appeared in train, the Committee seemed wary of over-tightening. Third, despite the staff forecast, the FOMC apparently considered the costs of waiting in terms of inflation risks to be small. Accordingly, they thought it better to put a rate increase on hold and see how the economy evolved. The June 2000 minutes contain a good deal of commentary supporting this interpretation: [29]

> The increasing though still tentative indications of some slowing in aggregate demand, together with the likelihood that the earlier policy tightening actions had not yet exerted their full retarding effects on spending, were key factors in this decision. The uncertainties surrounding the outlook for the economy, notably the extent and duration of the recent moderation in spending and the effects of the appreciable tightening over the past year . . . reinforced the argument for leaving the stance of policy unchanged at this meeting and weighting incoming data carefully. . . .Members generally saw little risk in deferring any further policy tightening move, particularly since the possibility that underlying inflation would worsen appreciably seemed remote under prevailing circumstances.

In the second half of 2000 it became increasingly evident that growth had slowed to a pace somewhat below trend and inflation was moving up at a slower pace than the staff had projected in June. The Committee's response was to hold the funds rate at 6.5 percent through the end of 2000. But the data around the turn of the year proved to be weaker than anticipated. In a conference call on January 3, 2001, the FOMC cut the funds rate to 6 percent and lowered it again to 5-1/2 percent at the end-of-month FOMC meeting.[30]

---

[29]The Committee had already invoked such arguments earlier in this cycle. As noted in the July 2000 Monetary Policy Report: "The FOMC considered larger policy moves at its first two meetings of 2000 but concluded that significant uncertainty about the outlook for the expansion of aggregate demand in relation to that of aggregate supply, including the timing and strength of the economy's response to earlier monetary policy tightenings, warranted a more limited policy action."

[30]At that meeting the Board staff was forecasting that growth would stagnate in the first half of the year, but that the economy would avoid an outright recession even with the funds rate at 5.75 percent. Core PCE inflation was projected to rise modestly to a little under 2.0 percent.

In justifying the aggressive ease, the minutes stated:

> Such a policy move in conjunction with the 50 basis point reduction in early January would represent a relatively aggressive policy adjustment in a short period of time, but the members agreed on its desirability in light of the rapid weakening in the economic expansion in recent months and associated deterioration in business and consumer confidence. The extent and duration of the current economic correction remained uncertain, but the stimulus ...would help guard against cumulative weakness in economic activity and would support the positive factors that seemed likely to promote recovery later in the year ...In current circumstances, members saw little inflation risk in such a "front-loaded" easing policy, given the reduced pressures on resources stemming from the sluggish performance of the economy and relatively subdued expectations of inflation.

According to this quote, not only was the actual weakening in activity an important consideration in the policy decision, but uncertainty over the extent of the downturn and the possibility that it might turn into an outright recession seemed to spur the Committee to make a large move. The "help guard against cumulative weakness" and "front-loaded" language could be read as the Committee taking out some additional insurance against the possibility that the weakening activity would snowball into a recession. This could have reflected a concern about the kinds of non-linear output dynamics or perhaps non-quadratic losses associated with a large recession that we discussed in Section 3.1.

The FOMC steadily brought the funds rate down further over the course of 2001 against the backdrop of weakening activity, and the economy seemed to be skirting a recession. Then the tragic events of September 11 occurred. There was, of course, huge uncertainty over how international developments, logistics disruptions, and the sentiment of households, businesses, and financial markets would affect spending and production. By November the staff was forecasting a modest recession: growth in the second half of 2001 was projected to decline 1-1/2 percent at an annual rate and rise at just a 1-1/4 percent rate in the first half of 2002. By the end of 2002 the unemployment rate was projected to rise to 6.1 percent and core PCE inflation was projected to be 1-1/2 percent. These forecasts were predicated on the funds rate remaining flat at 2-1/4 percent.

The FOMC, however, was worried about something more serious than the shallow recession forecast by the Staff. Furthermore, a new risk came to light, namely the chance that disinflationary pressures might emerge, that, once established, would be more difficult to fight with the funds rate already low. In response, the Committee again acted aggressively, cutting the funds rate 50 bps in a conference call on September 17 and again at their regular meetings in October and November. The November 2001 FOMC meeting minutes note:

> ...members stressed the absence of evidence that the economy was beginning to stabilize and some commented that indications of economic weakness had in fact intensified. Moreover, it was likely in the view of these members that core inflation, which was already modest, would decelerate further. In these circumstances insufficient monetary policy stimulus would risk a more extended contraction of the economy and possibly even downward pressures on prices that could be difficult to counter with the current federal funds rate already quite low. Should the economy display unanticipated strength in the near term, the emerging need for a tightening action would be a highly welcome development that could be readily accommodated in a timely manner to forestall any potential pickup in inflation.

This passage suggests that the large rate cuts were not only aimed at preventing the economy from falling into a serious recession with deflationary consequences, but that the Committee was also concerned that such an outcome "could be difficult to counter with the current funds rate already quite low." Accordingly, the aggressive policy moves could in part also have reflected insurance against the future possibility of being constrained by the ZLB, precisely the policy scenario and optimal policy prescription described in Section 2.

3.4 Quantifying references to uncertainty and insurance in FOMC Minutes

We have shown that Federal Reserve communications contain many references that suggest uncertainty or insurance motives influenced the stance of policy. But, has risk management had a material impact on policy? We now show how we quantified these references into variables that can be used to assess the importance of risk management for actual policy

decisions.

In the spirit of the narrative approach pioneered by Romer and Romer (1989), we built judgmental indicators based on our reading of the FOMC minutes covering the period from the beginning of Greenspan's chairmanship in 1987 to 2008. We concentrated on the paragraphs that describe the Committee's rationale for its policy decision, reading these passages for references to when uncertainty or insurance considerations appeared closely linked to the FOMC's decision. Other portions of the minutes were excluded from our analysis in order to better isolate arguments that directly influenced the policy decision from more general discussions of unusual data or forecast uncertainty.

We constructed two separate judgemental variables, one for uncertainty (hUnc) and one for insurance (hIns), where "h" stands for "human-coded." The uncertainty variable was coded to plus (minus) one if we judged that the Committee appealed to uncertainty to position the funds rate higher (lower) than it otherwise would be based on the staff forecast alone. If uncertainty did not appear to be an important factor influencing the policy decision, we coded the indicator as zero. We coded the insurance variable similarly by identifying when the minutes cited insurance against some adverse outcome as an important consideration in the stance of policy.[31]

As an example of our coding, consider the June 2000 meeting discussed above when the FOMC decided to wait to assess future developments before taking further policy action. The commentary below highlights the role of uncertainty in this decision (our italics):

> The increasing though still tentative indications of some slowing in aggregate demand, together with the likelihood that the earlier policy tightening actions had not yet exerted their full retarding effects on spending, were key factors in this decision. *The uncertainties surrounding the outlook for the economy, notably the extent and duration of the recent moderation in spending and the effects of the appreciable tightening over the past year,* including the 1/2 percentage point increase in the intended federal funds rate at the May meeting, *reinforced the*

---

[31]A value of plus (minus) one for either variable could reflect the Committee raising (lowering) rates by more (less) than they would have if they ignored uncertainty or insurance or a decision to keep the funds rate at its current level when a forecast-only call would have been to lower (raise) rates.

> *argument for leaving the stance of policy unchanged at this meeting and weighting incoming data carefully.*

We coded this meeting as a minus one for hUnc – rates were lower because uncertainty over the economic outlook and the effects of past policy moves appear to have been important factors in the Committee's decision not to raise rates. Similarly, the January and November 2001 quotes cited above led us to code hIns as a minus one for those meetings, since, as we noted in the narrative, the Committee appeared to be making aggressive rate moves in part to insure against downside risks to the baseline scenario.

We did not code all mentions of uncertainty or insurance as a plus or minus one. For example, the March 1998 minutes referred to uncertainties over the economic outlook and said that the Committee could wait for further developments before tightening to counter potential inflation developments. However, at that time the FOMC was not obviously in the midst of a tightening cycle; the baseline forecast seemed consistent with the funds rate setting at the time; and the commentary over the need to tighten was in reference to an indefinite point in the future. So, in our judgment, uncertainty did not appear to be a very important factor holding back a rate increase at this meeting and we coded it as a zero.[32]

Of course, this coding of the minutes is inherently subjective and there is no definitive way to judge the accuracy of the decisions we made. Consequently we also constructed objective measures of how often references to uncertainty or insurance appeared in the policy paragraphs of the minutes. In particular, we constructed variables which measure the percentage of sentences containing words related to uncertainty or insurance in conjunction with references to economic activity and/or inflation.[33] The measures for uncertainty and insurance are denoted mUnc and mIns, where "m" indicates these variables are "machine-coded."

Figures 4 and 5 show plots of our minutes-based uncertainty and insurance variables.

---

[32]From the minutes, " . . . should the strength of the economic expansion and the firming of labor markets persist, policy tightening likely would be needed at some point to head off imbalances that over time would undermine the expansion in economic activity. Most saw little urgency to tighten policy at this meeting, however . . . (o)n balance, in light of the uncertainties in the outlook and given that a variety of special factors would continue to contain inflation for a time, the Committee could await further developments bearing on the strength of inflationary pressures without incurring a significant risk . . . ."

[33]The appendix describes our coding algorithm in more detail.

Figure 4: Minutes-based uncertainty variables
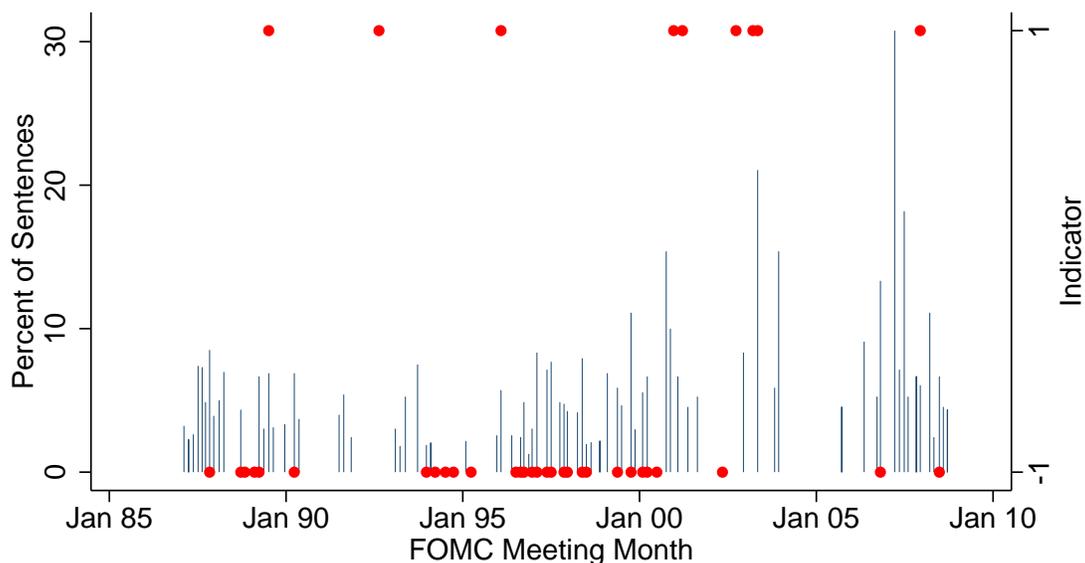
Non-zero values of the human-coded variables are indicated by red dots and the blue bars indicate the machine-coded sentence counts. The uncertainty indicator hUnc "turns on" in 31 out of the 128 meetings between 1993 and 2008. Indications that insurance was a factor in shading policy are not as common, but still show up 14 times in hIns. Most of the time – 24 for uncertainty and 11 for insurance – we judged that rates were set lower than they otherwise would have been to account for these factors.

The hUnc and hIns codings are not always reflected in the sentence counts. There are also meetings where the sentence counts are positive but we did not judge them to indicate that rates were set differently than they "normally" would have been. For example, in March of 2007 hUnc is coded zero for uncertainty whereas mUnc finds uncertainty referenced in nearly one-third of the sentences in the policy section of the minutes. Inspection of the minutes indicates that the Committee was uncertain over both the degree to which the economy

38

Figure 5: Minutes-based insurance variables
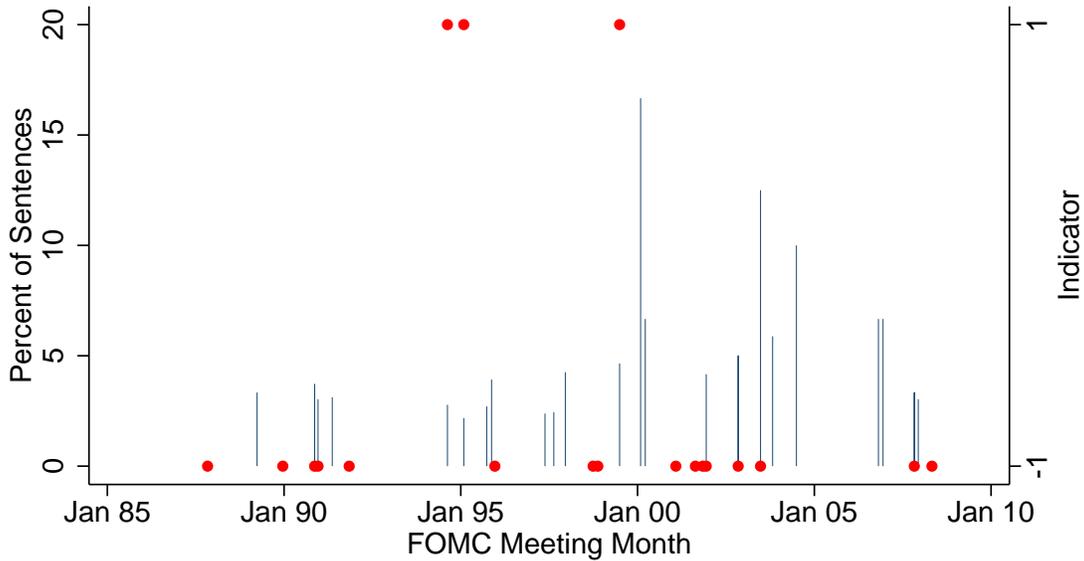
was weakening and whether their expectation of a decline in inflation, which was running uncomfortably high at the time, actually would materialize. In the end, they did not adjust current policy in response to these conflicting uncertainties. Hence we coded hUnc to zero in this case.

Note that we did not attempt to measure a variable for risk management *per se*. The minutes often contain discussions of policies aimed at addressing risks to attaining the Committee's goals. However, many times this commentary appears to surround policy adjustments aimed instead at balancing (possibly conflicting) risks to the outlook for output and inflation, not unlike the response to changes in economic conditions prescribed by the canonical framework for studying optimal policy under discretion. Such risk-balancing was discussed in our narrative of the 1997-1998 period.[34]

---

[34]Indeed, for much of our sample period, the Committee discussed risks about the future evolution of

4 Econometric evidence of risk management

So far we have uncovered clear evidence that risk management considerations have been a pervasive feature of Federal Reserve communications. But, it is not clear at this stage whether risk management has had a material impact on the FOMC's policy decisions. If it has, then calling for a risk management approach in the current policy environment would be consistent with a well-established approach to monetary policy. In this section we describe econometric evidence suggesting that risk management has had a material impact on the FOMC's funds rate choices in the pre-ZLB era.

We estimate monetary policy reaction functions of the kind studied in Clarida, Gali, and Gertler (2000) and many other papers. These have the funds rate set as a linear function of output gap and inflation forecasts; there is no role for risk management unless risk feeds directly into the point forecasts. To quantify the role of risk beyond such a direct influence we add variables that proxy for risk to the reaction function.[35]

4.1 Empirical strategy

Let R_t^* denote the *notional target* for the funds rate in period t. We assume the FOMC sets this target according to

$$R_t^* = R^* + \beta \left(E_t \left[\pi_{t,k} \right] - \pi^* \right) + \gamma E_t \left[x_{t,q} \right] + \mu s_t, \tag{13}$$

output or inflation in order to signal a possible bias in the direction of upcoming rate actions. For example, in the July 1997 meeting described earlier, the minutes indicate: "An asymmetric directive was consistent with their view that the risks clearly were in the direction of excessive demand pressures . . . " Since the Committee delayed tightening at this meeting, this "risk" reference communicated that the risks to price stability presented by the baseline outlook would likely eventually call for rate increases. But it does not appear to be a reference that variance or skewness in the distribution of possible inflation outcomes should dictate some non-standard policy response.

[35]There is a large literature that examines non-linearities in policy reaction functions (see Gnabo and Moccero (2014), Mumtaz and Surico (2015), and Tenreyro and Thwaites (2015) for reviews of this literature and recent estimates), but surprisingly little work that speaks directly to risk management. We discuss the related literature below.

where $\pi_{t,k}$ denotes the average annualized inflation rate from t to $t+k$, π^* is the FOMC's target for inflation, $x_{t,q}$ is the average output gap from t to $t+q$, s_t is a risk management proxy, and E_t denotes expectations conditional on information available to the FOMC at date t. The coefficients β, γ and μ are fixed over time. R^* is the desired nominal rate when inflation is at target, the output gap is closed and risk does not influence policy other than through the forecast, $\mu = 0$. If the average output and inflation gaps are both zero and the FOMC acts as if the natural rate is constant and out of its control, then $R^* = r^* + \pi^*$, where r^* is the real natural rate of interest.[36]

We make two more assumptions to arrive at our estimation equation. First, the FOMC has a preference for interest rate smoothing and so does not choose to hit its notional target instantaneously; as a practical matter it is necessary to include lags of the funds rate to fit the data. Second, the FOMC does not have perfect control over interest rates which gives rise to an error term υ_t. These assumptions lead to the following specification for the actual funds rate, R_t

$$R_t = (1 - A(1))R_t^* + A(L)R_{t-1} + \upsilon_t \tag{14}$$

where $A(L) = \sum_{j=0}^{N-1} a_{j+1}L^j$ is a polynomial in the lag operator L with N denoting the number of funds rate lags. The error term υ_t is assumed to be mean zero and serially independent. Combining (13) and (14) yields our estimation equation:

$$R_t = b_0 + b_1 E_t\left[\pi_{t,k}\right] + b_2 E_t\left[x_{t,q}\right] + A(L)R_{t-1} + b_3 s_t + \upsilon_t. \tag{15}$$

where b_i, $i = 0, 1, 2, 3$ are simple functions of $A(1)$, β, γ, μ, r^* and π^*.[37]

We use the publicly available Board staff forecasts of core CPI inflation (in percentage points) and the output gap (percentage point deviations of real GDP from its potential) to measure $E_t\left[\pi_{t,k}\right]$ and $E_t\left[x_{t,q}\right]$ with $k = q = 3$.[38] These forecasts are available for every FOMC

---

[36]There is no presumption that (13) reflects optimal policy and so assuming a constant natural rate is not inconsistent with our theoretical analysis. We explored using forecasted growth in potential output derived from Board staff forecasts to proxy for the natural rate and found this did not affect our results.

[37]We make no attempt to address the possibility of hitting the ZLB in our estimation. See Chevapatrakul, Kim, and Mizen (2009) and Kiesel and Wolters (2014) for papers that do this.

[38]The appendix describes our data in more detail.

meeting. We estimate (15) both meeting-by-meeting and quarter-by-quarter.[39] When we estimate (15) at the quarterly frequency we use staff forecasts corresponding to FOMC meetings closest to the middle of each quarter.[40] We measure R_t at the meeting frequency with the funds rate target announced (or estimated) at the end of the day of a meeting and at the quarterly frequency with the average target funds rate over the 30 trading days following the meeting closest to the middle of the quarter. Provided the error term υ_t is serially uncorrelated and is orthogonal to the forecasts and the risk proxies we can obtain consistent estimates of β, γ and μ by estimating (15) by ordinary least squares. We keep N sufficiently large to ensure that υ_t is serially uncorrelated.

To quantify the role of risk we study the magnitude and statistical significance of estimates of μ in (13). An insignificant estimate of μ cannot be interpreted as evidence against a role for risk management because risk might operate by influencing point forecasts as in our forward-looking model. We also could find no effect because risk might tilt policy in opposite directions depending on the circumstances. With the exception of our human-coded FOMC-based variables, none of our risk proxies accounts for the fact that perceived risks to the forecast might have different effects on policy depending on the nature of the risk and the state of the economy. For example, an increase in uncertainty about the inflation outlook should lead to tight policy if this increase occurs during a period of heightened concerns about rising inflation, but to looser policy if concerns are over unwanted disinflation. As such, estimates of the effect of any given proxy will at best reflect the nature of the risk and the circumstances in which it has arisen that have predominated over the sample period.

Finally, we do not allow for the coefficients on the forecasts to depend on our risk proxies as is suggested by the work of Brainard (1967) and others. However we show in the appendix that if these forecast coefficients are linear functions of risk then the null hypothesis that a given proxy's coefficient is zero in our now misspecified model encompasses the null that the forecast coefficients are invariant to risk as measured by that proxy.

---

[39]We assume meetings are equally spaced even though this is not true in practice. We account for this discrepancy when we calculate standard errors by allowing for heteroskedasticity.

[40]Gnabo and Moccero (2014) also estimate quarterly reaction functions using Board staff forecasts.

4.2 Proxies for risk management

In addition to our human- and machine-coded FOMC-based variables we consider several proxies for risk management that do not rely on interpreting the FOMC minutes. Two of these variables are constructed using the Board staff's forecast seen by the FOMC at their regular meetings and so we study them using our meeting frequency reaction functions. The remaining ones are measured at the quarterly frequency and can be divided into two groups based on whether they primarily reflect variance or skewness in the forecast.

The two additional FOMC-based proxies involve revisions to the Board staff's forecasts for the output gap (frGap) and core CPI inflation (frInf). The revisions correspond to changes between meeting m and $m - 1$ in the forecasts over the same one year period that starts in the quarter of meeting $m - 1$. A big change in the forecast is usually triggered by unusual events that may be difficult to interpret and hence generate uncertainty about the forecast. If the Committee was only worried about these events on its point forecast, then the post-shock forecasts of the output gap or inflation would be sufficient to describe the policy setting. However if uncertainty has a separate effect on policy then the forecast revisions might enter significantly.

Three of the quarterly proxies exploit financial market data: VXO, SPD and JLN. VXO is the Chicago Board Options Exchange's measure of market participants' expectations of S&P 500 stock index volatility over the next 30 days. Since the S&P 500 reflects earnings expectations VXO should, at least in part, measure market participants' uncertainty about the economic outlook.[41] SPD is the difference between the quarterly average of daily yields on BAA corporate bonds and 10 year Treasury bonds. Gilchrist and Zakrajšek (2012) demonstrate that this variable measures private-sector default risk plus other factors that may indicate downside risks to economic growth.[42] JLN is Jurado, Ludvigson, and Ng (2015)'s measure of the common variation in the one-year-ahead unforecastable components

---

[41]Using a VAR framework Bekaert, Hoerova, and Lo Duca (2013) find weak evidence that positive innovations to VXO lead to looser policy. Gnabo and Moccero (2014) find that policy responds more aggressively to economic conditions and is less inertial in periods of high uncertainty as measured by VXO.

[42]Alcidi, Flamini, and Fracasso (2011), Castelnuovo (2003) and Gerlach-Kristen (2004) consider reaction functions including SPD.

of a large number of activity, inflation and financial indicators. Given its basis in measuring uncertainty about macroeconomic forecasts JLN is a natural risk proxy to consider. But, unlike VXO and SPD, it does not measure real-time uncertainty, and similar to these two measures it confounds macroeconomic and financial uncertainty.

The remaining proxies are based on the Survey of Professional Forecasters (SPF) which surveys forecasters about their point forecasts of GDP growth and GDP deflator inflation and their probability distributions for these forecasts. We use both kinds of information to construct measures of variance and skewness in the economic outlook one year ahead.[43] Variance is measured using the median among forecasters of the standard deviations calculated from each individual's probability distribution (vGDP and vInf) and the interquartile range of point forecasts across individuals (DvGDP and DvInf.)[44] Skewness is measured using the median of the individual forecasters' mean minus mode (sGDP and sInf) and the difference between the mean and the mode of the cross-forecaster distribution of point forecasts (DsGDP and DsInf). So a positive (negative) value for one of these proxies represents upside (downside) risk to the modal forecast. The principle advantage of these proxies is that they are real-time measures of perceived risks in the forecast. The main drawback of the measures based on survey respondents' forecast distributions is that the bins they are asked to put probability mass on are relatively wide, so statistics based on them may contain substantial measurement error. The proxies based on the cross-section of forecasts are properly thought of as measuring forecaster disagreement rather than variance or skewness in the outlook *per se*. However there is a large literature that uses forecaster disagreement as a proxy for perceived risk.[45]

All estimates are based on samples that end in 2008 to avoid the ZLB period, but begin at different dates to address idiosyncratic features of the data. The benchmark start date is determined by the onset of Alan Greenspan's tenure on the FOMC in 1987, but later dates

---

[43]The forecast distributions are for growth and inflation in the current and following year. We use D'Amico and Orphanides (2014)'s procedure to translate these into distributions of four-quarter-ahead forecasts.

[44]Gnabo and Moccero (2014) find statistically insignificant effects of DvInf on monetary policy.

[45]As discussed by Baker, Bloom, and Davis (2015) there is no consensus on how good a proxy it is. Note that we do not study Baker et al. (2015)'s measure of uncertainty since it confounds uncertainty about monetary policy and the economic outlook.

are used in several cases. The sample for the FOMC-based indicators starts in 1993 because prior to then inter-meeting changes in the target funds rate were much more common then afterwards; the Committee often voted on a bias to future policy moves and the Chairman subsequently acted on his discretion. We cannot use inter-meeting moves because we lack contemporaneous staff forecasts. Furthermore the change in the frequency of inter-meeting moves raises the spectre of instability in the reaction function.[46] The pre-1993 inter-meeting moves are less of a concern for our quarterly models because in these specifications the funds rate is not as closely tied to any particular meeting. So we chose to include these data points to maximize the number of observations except when considering the proxies based on individuals' forecast distributions from the SPF. In these cases the first observation is 1992q1 to coincide with a discrete change in SPF methodology.[47]

Table 4: Summary statistics for the FOMC-based risk proxies

| Variable | Obs. | Mean | Std. Dev. | Min | Max | Correlation with forecast of | |
						Inflation	Output gap
Inflation forecast	128	2.45	0.45	1.30	3.53	1.00	0.21
Output gap forecast	128	-0.14	1.58	-4.85	3.08	0.21	1.00
hUnc	128	-0.13	0.48	-1	1	-0.23	-0.33
hIns	128	-0.06	0.33	-1	1	0.18	0.15
mUnc	128	2.92	4.80	0	30.8	-0.06	0.14
mIns	128	0.83	2.45	0	16.7	-0.10	0.08
frInf	128	-0.01	0.18	-0.63	0.63	0.23	0.01
frGap	128	-0.01	0.41	-2.00	0.77	0.24	0.29

Tables 4 and 5 display summary statistics for Board staff forecasts of inflation and the output gap and the various proxies for risk management at the meeting and quarterly fre-

---

[46]Between 1990 and 1992 only 4 of the 18 changes in the funds rate target occurred at a meeting. In contrast, between 1993 and 2008, 54 of the 61 changes in the funds rate target occurred at FOMC meetings. Ignoring inter-meeting moves causes specification problems if interest rate smoothing is a function of not just time, but also the number of policy moves. Indeed, when we estimated our meeting frequency models starting in 1987 our point estimates are (statistically) similar, but even with 5 funds rate lags substantial serial correlation remained in the residuals.

[47]In 1992 the SPF narrows the bins it uses to summarize the forecast probability distributions of individual forecasters. See D'Amico and Orphanides (2014) and Andrade, Ghysels, and Idier (2013) for attempts to address this change in bin sizes.

Table 5: Summary statistics for quarterly risk proxies

Variable	Obs.	Mean	Std. Dev.	Min	Max	Correlation with forecasts of	
						Inflation	Output Gap
Inflation forecast	86	2.97	1.02	1.33	5.32	1.00	-0.04
Output gap forecast	86	-0.45	1.69	-4.4	3.08	-0.04	1.00
VXO	86	21.0	8.48	10.6	62.1	-0.02	0.04
JLN	86	0.96	0.05	0.89	1.22	-0.06	-0.04
vInf	68	0.74	0.06	0.6	0.90	-0.22	-0.08
vGDP	68	0.9	0.12	0.67	1.30	-0.22	0.22
DvInf	86	0.6	0.18	0.24	1.10	0.25	-0.35
DvGDP	86	0.73	0.27	0.3	1.64	0.37	-0.05
SPD	86	2.11	0.65	1.37	5.60	-0.34	-0.34
sInf	68	0.05	0.08	-0.12	0.30	0.23	-0.12
sGDP	68	-0.10	0.19	-0.54	0.47	-0.10	-0.48
DsInf	86	0.06	0.20	-0.5	0.51	0.01	-0.23
DsGDP	86	0.3	0.27	-0.5	0.90	-0.22	0.21

quencies. The main thing to notice from these tables is that no risk proxy displays a particulary large positive or negative correlation with either the output gap or inflation forecast. This suggests that our proxies contain information that is not already incorporated into these forecasts. Nevertheless there are some variables with moderately large correlations in absolute value so the forecasts do reflect underlying risks to the outlook to some extent. Interestingly, skewness in forecasters' GDP forecasts (sGDP) is relatively strongly *negatively* correlated with the outlook for activity.

Table 6: Cross-correlations of FOMC-based risk proxies

Variable	hUnc	hIns	mUnc	mIns	frInf
hIns	-0.05				
mUnc	-0.07	0.02			
mIns	-0.13	-0.09	0.04		
frInf	0.10	0.05	-0.07	0.06	
frGap	-0.11	0.08	0.05	0.11	0.25

Tables 6 and 7 display cross-correlations of the FOMC-based and quarterly proxies, re-

spectively. As suggested by Figures 4 and 5 the human and machine coded FOMC variables for uncertainty and insurance are essentially uncorrelated. These variables also appear unrelated to the forecast revision variables. Several correlations among the quarterly proxies are worth noting. Forecaster variance and disagreement about the GDP growth outlook (vGDP and DvGDP) are both positively correlated with VXO and SPD, suggesting the financial variables do reflect to some extent uncertainty about the growth outlook. Also, the relatively high correlation of SPD with sGDP suggests the former to some extent captures skewness in the growth outlook. The correlation of vGDP with vInf and DvGDP with DvInf are both fairly large suggesting uncertainty about inflation and GDP often move together. The correlations of the corresponding forecaster uncertainty and disagreement variables (vGDP with DvGDP and vInf with DvInf) are somewhat large too. Evidently disagreement among forecasters is similar to the median amount of uncertainty they see. Finally Jurado et al. (2015)'s measure of macroeconomic uncertainty JLN is highly correlated with VXO and SPD and to some extent DvGDP, but much less so with any of the other risk proxies.

Table 7: Cross-correlations of quarterly risk proxies

Variable	VXO	JLN	vInf	vGDP	DvInf	DvGDP	SPD	sInf	sGDP	DsInf
JLN	0.54									
vInf	0.04	0.23								
vGDP	0.40	0.29	0.40							
DvInf	0.15	0.18	0.29	0.03						
DvGDP	0.54	0.38	0.16	0.37	0.33					
SPD	0.73	0.67	0.15	0.32	0.26	0.35				
sInf	-0.27	-0.11	0.29	-0.16	0.08	-0.14	-0.18			
sGDP	0.21	0.22	-0.09	-0.04	0.25	0.16	0.43	-0.15		
DsInf	-0.28	-0.17	0.10	-0.24	0.13	-0.14	-0.08	0.04	0.15	
DsGDP	0.07	-0.08	0.04	0.10	-0.22	0.08	0.02	-0.08	-0.17	-0.17

4.3 Policy rule findings

Table 8 shows our policy rule estimates with and without the various FOMC-based variables; Tables 9 and 10 show estimates with and without the quarterly variance and skewness proxies.

Except for the human coded variables hUnc and hIns, prior to estimation the risk proxies have been normalized to have mean zero and unit standard deviation so their coefficients indicate percentage point responses of the funds rate to standard deviation changes. The tables have the same layout: the first column shows the policy rule excluding any risk proxies and the other columns show the policy rules after adding the indicated risk proxy. The coefficient associated with a given risk proxy corresponds to an estimate of μ in (13). The speed of adjustment to the notional funds rate target $(\sum_{j=1}^{N} a_j)$ and the coefficients on the forecasts of inflation (β) and the output gap (γ) are similar across specifications and consistent with estimated forecast-based policy rules in the literature.

Table 8: FOMC-based risk proxies in monetary policy rules

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\sum_{j=1}^{5} a_j$	.81***	.80***	.81***	.80***	.81***	.84***	.81***
	(.03)	(.03)	(.03)	(.03)	(.03)	(.03)	(.04)
β	1.89***	1.95***	1.86***	1.90***	1.89***	1.75***	1.89***
	(.17)	(.16)	(.17)	(.17)	(.17)	(.22)	(.17)
γ	.85***	.88***	.85***	.83***	.85***	.80***	.85***
	(.05)	(.05)	(.05)	(.05)	(.05)	(.06)	(.06)
hUnc		.40**					
		(.16)					
hIns			.48				
			(.45)				
mUnc				.11*			
				(.06)			
mIns					-.0006		
					(.05)		
frGap						.47**	
						(.19)	
frInf							-.009
							(.14)
LM	.31	.07	.59	.58	.31	.63	.20
Obs.	128	128	128	128	128	128	128

Note: Superscripts ***, ** and * indicate statistical significance at the 1, 5 and 10 percent levels. Standard errors are robust to heteroskedasticity. Entries in the "LM" row are p-values of Durbin's test for the null hypothesis of no serial correlation in the residuals up to fifth order.

From Table 8 we see that the coefficient on the human coding of uncertainty (hUnc) is statistically significant at the 5% level and it indicates that when uncertainty has shaded the policy decision above or below the forecast-only prescription it has moved the notional target by 40 bps. With interest rate smoothing the immediate impact is much smaller; the 95% confidence interval is 2-14 bps. The machine coding of uncertainty (mUnc) is significant at the 10% level but the effect is small. The insurance indicators (hIns and mIns) are not significant, but the point estimate of the hIns coefficient is similar to its uncertainty counterpart. The coefficient on the output gap forecast revision variable (frGap) is large and significant, indicating a one standard deviation positive surprise in the forecast raises the notional target by 47 bps over and above the impact this surprise has on the forecast itself.[48] In contrast, revisions to the inflation outlook (frInf) do not influence policy beyond their direct effect on the forecast.

Table 9 shows clear evidence that variance in the economic outlook has shaded policy away from the forecast-only prescription. The coefficients on VXO and JLN are both statistically and economically significant with one standard deviation increases lowering the notional target funds rate by 43 and 29 bps.[49] Disagreement over the GDP forecast (DvGDP) has a significant coefficient which is similar to the ones for VXO and JLN, suggesting that the latter variables' correlation with monetary policy reflects uncertainty in the growth outlook. That all these coefficients are negative suggests that higher uncertainty about growth has influenced the FOMC when it was concerned about recessionary dynamics and lowered the funds rate more than prescribed by the forecast alone. The only other significant coefficient in Table 9 corresponds to the measure of individual forecasters' views about the uncertainty in their inflation forecasts (vInf). In this case uncertainty shades the policy higher, by about 20 bps. This suggests that higher uncertainty about the inflation forecast has influenced the FOMC when it was concerned about inflation rising above desired levels and raised rates

---

[48]The magnitude and significance of this coefficient is largely driven by the sharp decline in the funds rate in 2008 that occurred alongside substantial downward revisions to the output gap forecast.

[49]The JLN variable can be expressed as a linear combination of the three uncertainty measures constructed with the underlying activity, inflation, and financial indicators separately. We used Jurado et al. (2015)'s replication software to separate out these components, and found that the estimated effects of JLN are driven primarily by the financial indicators.

Table 9: Quarterly variance proxies in monetary policy rules

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\sum_{j=1}^{2} a_j$	.69***	.69***	.70***	.70***	.69***	.69***	.69***
	(.03)	(.03)	(.03)	(.04)	(.04)	(.04)	(.03)
β	1.73***	1.73***	1.72***	2.21***	2.13***	1.75***	1.88***
	(.12)	(.11)	(.12)	(.17)	(.16)	(.11)	(.13)
γ	.80***	.84***	.81***	.78***	.77***	.78***	.81***
	(.06)	(.06)	(.06)	(.07)	(.06)	(.07)	(.06)
VXO		-.43***					
		(.11)					
JLN			-.29***				
			(.09)				
vInf				.21**			
				(.10)			
vGDP					.03		
					(.12)		
DvInf						-.09	
						(.13)	
DvGDP							-.38***
							(.13)
LM	.53	.56	.86	.71	.59	.52	.86
Obs.	86	86	86	68	68	86	86

Note: Superscripts ***, ** and * indicate statistical significance at the 1, 5 and 10 percent levels. Standard errors are robust to heteroskedasticity. Entries in the "LM" row are p-values of Durbin's test for the null hypothesis of no serial correlation in the residuals up to second order.

above levels prescribed by the baseline forecast.

Similarly strong evidence that skewness has mattered for policy decisions is found in Table 10. The coefficients on the interest rate spread indicator of downside risks to activity (SPD), skewness in the outlook for inflation measured from forecasters' own forecast distributions (sInf) and skewness in the inflation outlook measured across point forecasts (DsInf) are all significant. An increase in perceived downside risks to activity lowers the funds rate, while an increase in perceived upside risks to inflation raises it. The effects seem large; increases in the skewness proxies change the notional target by -56, 23 and 40 bps, respectively. These findings reinforce those for the variance proxies and similarly seem consistent with our reading

Table 10: Quarterly skewness proxies in monetary policy rules

	(1)	(2)	(3)	(4)	(5)	(6)
$\sum_{j=1}^{2} a_j$	.69***	.68***	.71***	.70***	.72***	.69***
	(.03)	(.03)	(.04)	(.04)	(.03)	(.03)
β	1.73***	1.55***	2.02***	2.09***	1.74***	1.69***
	(.12)	(.11)	(.16)	(.16)	(.10)	(.12)
γ	.80***	.71***	.80***	.74***	.89***	.81***
	(.06)	(.06)	(.07)	(.08)	(.08)	(.07)
SPD		-.56***				
		(.14)				
sInf			.23**			
			(.10)			
sGDP				-.15		
				(.11)		
DsInf					.40***	
					(.13)	
DsGDP						-.16
						(.12)
LM	.53	.90	.34	.67	.61	.62
Obs.	86	86	68	68	86	86

Note: Superscripts ***, ** and * indicate statistical significance at the 1, 5 and 10 percent levels. Standard errors are robust to heteroskedasticity. Entries in the "LM" row are p-values of Durbin's test for the null hypothesis of no serial correlation in the residuals up to second order.

of FOMC communications. The point estimates for skewness in the GDP outlook (sGDP and DsGDP) have surprisingly negative signs. However these coefficients are relatively small and insignificant.

Taken together, these results indicate that risk management concerns broadly conceived have had a statistically and economically significant impact on policy decisions over and above how those concerns are reflected in point forecasts. The effects we find suggest that the Committee acted aggressively to offset concerns about declining growth or rising inflation. We conclude from this econometric analysis that risk management does not just appear in the words of the FOMC – it is reflected in their deeds as well.

5   Conclusion

We have focused on risk surrounding the forecast as a relevant consideration for monetary policy near the ZLB, but other issues are relevant to the liftoff calculus as well. In particular, policymakers may face large reputational costs of reversing a decision. Empirically, it is well known that central banks tend to go through "tightening" and "easing" cycles which in turn induce substantial persistence in the short-term interest rate. Uncertainty over the outlook may be one reason for this persistence. But another reason why policymakers might be reluctant to reverse course is that it would damage their reputation, perhaps because the public would lose confidence in the central bank's ability to understand and stabilize the economy. With high uncertainty, this reputation element would lead to more caution. In the case of liftoff, it argues for a longer delay in raising rates to avoid the reputational costs of reverting back to the ZLB.

Another reputational concern is the signal the public might infer about the central bank's commitment to its stated policy goals. With regard to liftoff, suppose it occurred with output or inflation still far below target. Large gaps on their own pose no threat to the central bank's credibility if the public is confident that the economy is on a path to achieve its objectives in a reasonable period of time and that it is willing to accommodate this path. However, if there is uncertainty over the strength of the economy, early liftoff might be construed as a less-than-enthusiastic endorsement of the central bank's ultimate policy objectives. Motivated by the current situation, we have focused in the paper on the case of a central bank that is undershooting its inflation target, but similar issues would arise if risk management considerations dictated an aggressive tightening to guard against inflation and the central bank failed to act accordingly. In a wide class of models such losses of credibility can have deleterious consequences for achieving the central bank's objectives.

References

Adam, K. and R. M. Billi (2007). Discretionary monetary policy and the zero lower bound on nominal interest rates. *Journal of Monetary Economics 54*(3), 728–752.

Alcidi, C., A. Flamini, and A. Fracasso (2011). Policy regime changes, judgment and taylor rules in the greenspan era. *Economica 78*, 89–107.

Andrade, P., E. Ghysels, and J. Idier (2013). Tails of inflation forecasts and tales of monetary policy. UNC Kenan-Flagler Research Paper No. 2013-17.

Baker, S. R., N. Bloom, and S. J. Davis (2015). Measuring economic policy uncertainty. Stanford University manuscript.

Barlevy, G. (2011). Robustness and macroeconomic policy. *Annual Review of Economics 3*, 1–24.

Barsky, R., A. Justiniano, and L. Melosi (2014). The natural rate and its usefulness for monetary policy making. *American Economic Review 104*(4), 37–43.

Basu, S. and B. Bundick (2013). Downside risk at the zero lower bound. Boston College Manuscript.

Bekaert, G., M. Hoerova, and M. Lo Duca (2013). Risk, uncertainty and monetary policy. *Journal of Monetary Economics 60*, 771–788.

Bernanke, B. S. (2012). The changing policy landscape. In *Monetary Policy Since the Onset of the Crisis*, Economic Policy Symposium, pp. 1–22. Federal Reserve Bank of Kansas City.

Bloom, N. (2009). The effect of uncertainty shocks. *Econometrica 77*(3), 623–685.

Bomfin, A. and L. Meyer (2010). Quantifying the effects of fed asset purchases on treasury yields. Macroeconomics Advisors, Monetary Policy Insights: Fixed Income Focus.

Born, B. and J. Pfeifer (2014). Policy risk and the business cycle. *Journal of Monetary Economics 68*, 68–85.

Brainard, W. (1967). Uncertainty and the effectiveness of policy. *American Economic Review 57*(2), 411–425.

Campbell, J. R., C. L. Evans, J. D. Fisher, and A. Justiniano (2012). Macroeconomic effects of federal reserve forward guidance. *Brookings Papers on Economic Activity Spring*, 1–54.

Castelnuovo, E. (2003). Taylor rules, omitted variables, and interest rate smoothing in the US. *Economics Letters 81*, 55–59.

Chen, H., V. Curida, and A. Ferrero (2012). The macroeconomic effects of large scale asset purchase programmes. *Economic Journal 122*, 289–315.

Chevapatrakul, T., T. Kim, and P. Mizen (2009). The Taylor principle and monetary policy approaching a zero bound on nominal rates: Quantile regression results for the united states and japan. *Journal of Money, Credit and Banking 41*(8), 1705–1723.

Christiano, L., M. Eichenbaum, and C. Evans (2005). Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy 113*(1), 1–45.

Clarida, R., J. Gali, and M. Gertler (2000). Monetary policy rules and macroeconomic stability: Evidence and some theory. *Quarterly Journal of Economics CXV*(1), 147–180.

Coibion, O., Y. Gorodnichenko, and J. Wieland (2012). The optimal inflation rate in new keynesian models: Should central banks raise their inflation targets in light of the zero lower bound? *Review of Economic Studies 79*(4), 1371–1406.

Cúrdia, V., A. Ferrero, Ging Cee Ng, and A. Tambalotti (2015). Has U.S. monetary policy tracked the efficient interest rate. *Journal of Monetary Economics 70*, 72–83.

D'Amico, S. and T. King (2013). Flow and stock effects of large-scale treasury purchases: Evidence on the importance of local supply. *Journal of Financial Economics 108*, 425–448.

D'Amico, S. and T. King (2015). Policy expectations, term premia, and macroeconomic performance. Federal Reserve Bank of Chicago manuscript.

D'Amico, S. and A. Orphanides (2014). Inflation uncertainty and disagreement in bond risk premia. Chicago Fed working paper 2014-24.

Dolado, J. J., P. R. María-Dolores, and M. Naveira (2005). Are monetary policy reaction functions asymmetric?: The role of nonlinearity in the phillips curve. *European Economic Review 49*(2), 485–503.

Dolado, J. J., P. R. María-Dolores, and F. J. Ruge-Murcia (2004). Nonlinear monetary policy rules: Some new evidence for the us. *Studies in Nonlinear Dynamics and Econometrics 8*(3).

Egertsson, G. B. and M. Woodford (2003). The zero bound on interest rates and optimal monetary policy. *Brookings Papers on Economic Activity 2003*(1), 139–211.

Eichenbaum, M. and J. D. Fisher (2007). Esimating the frequency of price re-optimization in calvo-style models. *Journal of Monetary Economics 54*(7), 2032–2047.

Engen, E. M., T. T. Laubach, and D. Reifschneider (2015). The macroeconomic effects of the federal reserve's unconventional monetary policy. Finance and Ecnomics Discussion Series 2012-5, Board of Governors of the Federal Reserve System.

English, W. B., D. López-Salido, and R. Tetlow (2013). The federal reserve's framework for monetary policy – rcent changes and new questions. Federal Reserve Board, Finance and Economics Discussion Series 2013-76.

Evans, C. L. (2014). Patience is a virtue when normalizing monetary policy. Text of speech to Peterson Institute for International Economics.

Fernández-Villaverde, J., P. Guerró-Quintana, K. Kuester, and J. Rubio-Ramírez (2012). Fiscal volatility shocks and economic activity. Philladelphia Fed Working Paper No. 11-32/R.

Fuhrer, J. C. (2000). Habit formation in consumption and its implications for monetary-policy models. *America Economic Review 90*(3), 367–390.

Gagnon, J., M. Raskin, J. Remache, and B. Sack (2010). Optimal fiscal and monetary policy with occasionally binding zero bound constraints. Federal Reserve Bank of New York Staff Report No. 441.

Gali, J. (2008). *An Introduction to the New Keynesian Framework*. Princeton, NJ: Princeton University Press.

Gali, J. and M. Gertler (1999). Inflation dynamics: a structural econometric analysis. *Journal of Monetary Economics 44*, 192–222.

Gerlach-Kristen, P. (2004). Interest rate smoothing: Monetary policy inertia or unobserved variables. *Contributions in Macroeconomics 4*(1), 1534–6005.

Gilchrist, S. and E. Zakrajšek (2012). Credit spreads and business cycle fluctuations. *American Economic Review 102*(4), 1692–1720.

Gnabo, J. and D. N. Moccero (2014). Risk management, nonlinearity and agressiveness in monetary policy: The case of the US Fed. *Journal of Banking & Finance*.

Goodfriend, M. (1991). Interest rates and the conduct of monetary policy. *Carnegie-Rochester Conference Series on Public Policy 34*, 7–30.

Greenspan, A. (2004). Risk and uncertainty in monetary policy. *American Economic Review 94*(2), 33–40.

Hamilton, J. and J. Wu (2010). The effectiveness of alternative monetary policy tools in a zero lower bound environment. UCSD manuscript.

Hamilton, J. D., E. S. Harris, J. Hatzius, and K. D. West (2015). The equilibrium real funds rate: Past, present and future. UCSD manuscript.

Hansen, L. and T. Sargent (2008). *Robustness*. Princeton, NJ: Princeton University Press.

Jurado, K., S. Ludvigson, and S. Ng (2015). Measuring uncertainty. *American Economic Review 105*(3), 1177–1276.

Kiesel, K. and M. H. Wolters (2014). Estimating monetary policy rules when the zero lower bound on nominal interest rates is approached. Kiel Working Paper No. 1898.

Kiley, M. T. (2012). The aggregate demand effects of short- and long-term interest rates. Finance and Ecnomics Discussion Series 2012-54, Board of Governors of the Federal Reserve System.

Kilian, L. and S. Manganelli (2008). The central banker as a risk manager: Estimating the federal reserve's preferences under greenspan. *Journal of Money, Credit and Banking 40*(6).

Krishnamurthy, A. and A. Vissing-Jorgensen (2013). The ins and outs of lsaps. Kansas City Federal Reserve Symposium on Global Dimensions of Unconventional Monetary Policy.

Krugman, P. R. (1998). It's baaack: Japan's slump and the return of the liquidity trap. *Brookings Papers on Economic Activity Fall*, 137–187.

Laubach, T. and J. C. Williams (2003). Measuring the natural rate of interest. *The Review of Economics and Statistics 85*(4), 1063–1070.

Laxton, D., D. Rose, and D. Tambakis (1999). The U.S. phillips curve: The case for asymmetry. *Journal of Economic Dynamics & Control 23*, 1459–1485.

Mas-Colell, A., M. D. Whinston, and J. R. Green (1995). *Microeconomic Theory*. Oxford, United Kingdom: Oxford University Press.

Mumtaz, H. and P. Surico (2015). The transmission mechanism in good and bad times. Forthcoming *International Economic Review*.

Nakata, T. (2013a). Optimal fiscal and monetary policy with occasionally binding zero bound constraints. Finance and Ecnomics Discussion Series 2013-40, Board of Governors of the Federal Reserve System.

Nakata, T. (2013b). Uncertainty at the zero lower bound. Finance and Ecnomics Discussion Series 2013-09, Board of Governors of the Federal Reserve System.

Nakata, T. and S. Schmidt (2014). Conservatism and liquidity traps. Finance and Ecnomics Discussion Series 2014-105, Board of Governors of the Federal Reserve System.

Nakov, A. A. (2008). Optimal and simple monetary policy rules with zero floor on the nominal interest rate. *International Journal of Central Banking 4*(2), 73–127.

Orphanides, A. and J. C. Williams (2002). Robust monetary policy rules with unknown natural rates. *Brookings Papers on Economic Activity Fall*, 63–145.

Reifschneider, D. and J. C. Williams (2000, November). Three lessons for monetary policy in a low-inflation era. *Journal of Money, Credit, and Banking 32*(4), 936–966.

Romer, C. D. and D. H. Romer (1989). Does monetary policy matter? a new test in the spirit of friedman and schwartz. In O. Blanchard and S. Fischer (Eds.), *NBER Macroeconomics Annual 2005*, Volume 4.

Rudebusch, G. and L. E. Svensson (1999). Policy rules for inflation targeting. In J. B. Taylor (Ed.), *Monetary Policy Rules*. Chicago, IL: University of Chicago Press.

Rudebusch, G. D. (2002). Term structure evidence on interest rate smoothing and monetary policy inertia. *Journal of Monetary Economics 49*, 1161–1187.

Sack, B. (2000). Does the fed act gradually? a var analysis. *Journal of Monetary Economics 46*(1), 229–256.

Smets, F. and R. Wouters (2007). Shocks and frictions in US business cycles: A Bayesian DSGE approach. *The American Economic Review 97*(3), 586–606.

Surico, P. (2007). The fed's monetary policy rule and U.S. inflation: The case of asymmetric preferences. *The Journal of Economic Dynamics & Control 31*, 305–324.

Svensson, L. and M. Woodford (2002). Optimal policy with partial information in a forward-looking model: Certianty-equivalence redux. Manuscript.

Svensson, L. and M. Woodford (2003). Indicator variables for optimal policy. *Journal of Monetary Economics 50*, 691–720.

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

Tenreyro, S. and G. Thwaites (2015). Pushing on a string: US monetary policy is less powerful in recessions. Manuscript.

Werning, I. (2012). Managing a liquidity trap: Monetary and fiscal policy. MIT Manuscript.

Woodford, M. (2003). *Interest and Prices*. Princeton, NJ: Princeton University Press.

Woodford, M. (2012). The changing policy landscape. In *Methods of Policy Accommodation at the Interest-Rate Lower Bound*, Economic Symposium, pp. 185–288. Federal Reserve Bank of Kansas City.

Working Paper Series

A series of research studies on regional economic issues relating to the Seventh Federal Reserve District, and on financial and economic topics.

Examining Macroeconomic Models through the Lens of Asset Pricing   **WP-12-01**
Jaroslav Borovička and Lars Peter Hansen

The Chicago Fed DSGE Model   **WP-12-02**
Scott A. Brave, Jeffrey R. Campbell, Jonas D.M. Fisher, and Alejandro Justiniano

Macroeconomic Effects of Federal Reserve Forward Guidance   **WP-12-03**
Jeffrey R. Campbell, Charles L. Evans, Jonas D.M. Fisher, and Alejandro Justiniano

Modeling Credit Contagion via the Updating of Fragile Beliefs   **WP-12-04**
Luca Benzoni, Pierre Collin-Dufresne, Robert S. Goldstein, and Jean Helwege

Signaling Effects of Monetary Policy   **WP-12-05**
Leonardo Melosi

Empirical Research on Sovereign Debt and Default   **WP-12-06**
Michael Tomz and Mark L. J. Wright

Credit Risk and Disaster Risk   **WP-12-07**
François Gourio

From the Horse's Mouth: How do Investor Expectations of Risk and Return
Vary with Economic Conditions?   **WP-12-08**
Gene Amromin and Steven A. Sharpe

Using Vehicle Taxes To Reduce Carbon Dioxide Emissions Rates of
New Passenger Vehicles: Evidence from France, Germany, and Sweden   **WP-12-09**
Thomas Klier and Joshua Linn

Spending Responses to State Sales Tax Holidays   **WP-12-10**
Sumit Agarwal and Leslie McGranahan

Micro Data and Macro Technology   **WP-12-11**
Ezra Oberfield and Devesh Raval

The Effect of Disability Insurance Receipt on Labor Supply: A Dynamic Analysis   **WP-12-12**
Eric French and Jae Song

Medicaid Insurance in Old Age   **WP-12-13**
Mariacristina De Nardi, Eric French, and John Bailey Jones

Fetal Origins and Parental Responses   **WP-12-14**
Douglas Almond and Bhashkar Mazumder

Working Paper Series *(continued)*

Working Paper Series *(continued)*

Working Paper Series *(continued)*

Working Paper Series *(continued)*

Working Paper Series *(continued)*