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Lift-off Uncertainty

What Can We Infer From the FOMC's Summary of Economic Projections?

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Advisor : Prof. Carlos Viana de Carvalho
Co–Advisor: Prof. Tiago Couto Berriel

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Resumo

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Quando a política monetária está restrita ao limite inferior da taxa de juros, fazer inferência sobre o comportamento do Banco Central se torna mais difícil. Por consequência, apesar de esforços das autoridades monetárias para minimizar esse efeito através de comunicação mais ativa, a incerteza sobre política monetária tende a aumentar. Em particular, a incerteza sobre o grau de comprometimento aos planos de política se torna crucial. Usando modelos Novo Keynesianos sujeitos ao limite inferior da taxa de juros, quantifica-se a incerteza sobre projeções da taxa de juros. O primeiro passo involve caracterizar o grau de comprometimento do Fed em prover acomodação por períodos de tempo prolongados. Para tanto, calibra-se versções dos models sob diferentes hipóteses em relação ao grau de comprometimento de política, e descobre-se qual especificação apresenta um melhor ajuste aos dados do SEP. Em seguida, usa-se a melhor especificação para construir bandas de incerteza ao redor das projeções da taxa de juros, obtidas simulando respostas da política monetária aos eventos econômicos futuros. Os resultados sugerem que o grau de comprometimento do Fed diminuiu no passado recente. Quantitativamente, a projeção mediana indica que a subida da taxa de juros vai acontecer em 2015Q3, mas há riscos de que a taxa permaneça em zero até o terceiro trimestre de 2016.

Palavras–chave

Incerteza no Aperto Monetário; Resumo de Projeções Econômicas; Limite Inferior da Taxa de Juros;

Abstract

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When the policy rate is constrained by the zero lower bound (ZLB), inference about central bank behavior becomes more difficult. As a result, despite possible efforts by the monetary authority to counteract this effect through more active communication, policy uncertainty tends to increase. In particular, uncertainty about the degree of commitment to policy plans becomes key. We use standard New Keynesian models subject to the ZLB to quantify the uncertainty around interest rate forecasts. The first step involves an assessment of the degree of Fed commitment to provide accommodation for extended periods of time. To that end, we calibrate versions of the models under different assumptions about the degree of policy commitment, and assess which specification provides the best fit to the so-called "SEP dots." We then use the best-fitting specification to construct uncertainty bands around interest rate forecasts, obtained by simulating policy responses to economic developments going forward. Our results suggest that the degree of Fed commitment to low rates for an extended period of time decreased in the recent past. Quantitatively, our median projection indicates that lift-off will occur in 2015Q3, but there is some risk that rates will remain at zero until the third quarter of 2016.

Keywords

Lift-off Uncertainty; Summary of Economic Projections; Zero Lower Bound;

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1
Introduction

Economic theory suggests that the behavior of the economy can differ markedly depending on whether the central bank conducts policy in a discretionary fashion, or commits to a plan from which it might wish to deviate on occasion. In normal circumstances, joint observation of the evolution of the state of the economy and of policy decisions allows one to check if a previously specified state-contingent plan is being followed. Once the economy hits the interest rate zero lower bound (ZLB), however, inferring central bank behavior becomes both more difficult and more important. Being stuck at zero, the main monetary policy instrument does not react to the state of the economy. As a result, the central bank needs to resort to so-called unconventional policies: balance sheet actions, and more active communication (forward guidance). Theory suggests that promises to keep interest rates low after the economy recovers have stimulative effects today, through higher inflation expectations. However, time-consistency issues are key in this context. Krugman (1998) points out that this policy involves a commitment to inflate beyond the central bank's "comfort zone", promising low interest rates for a long period of time. Discretionary policy would react earlier to inflation developments and, thus, optimal policy under a credible commitment stimulates the economy more than a discretionary policy, despite the fact that they involve exactly the same interest rate in the initial periods of policy implementation - namely, zero. As a consequence inference about the degree of commitment becomes a key source of uncertainty about the future path of interest rates.

But how can we infer the degree of policy commitment when at the ZLB? In this paper we try to address this question by using information provided in the Fed's Summary of Economic Projections (SEP). Since January 2012, the Fed has disclosed its members' views on the future path of the target interest rate under appropriate monetary policy.[1] Figure 1.1 reproduces the SEP interest rate forecasts released in June 2014. These forecasts – the so-called "SEP dots" – indicate individual participant's judgment of the appropriate level of the target federal funds rate at various points in the future. SEP projections are conditional on information about the state of the economy available at the time. If, at a certain point in time, there was a fully state-contingent plan for

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[1] The SEP already contained information on participants' forecasts of the unemployment rate, the change in real GDP, inflation and core inflation rate at different points in time, under appropriate monetary policy.

interest rates going forward, one would be able to asses whether, over time, these projections remained in line with that state contingent plan. Deviations from the path of interest rates implied by an earlier state-contingent plan can thus be informative of whether the Fed has re-optimized every period, or followed some sort of “partial commitment”.

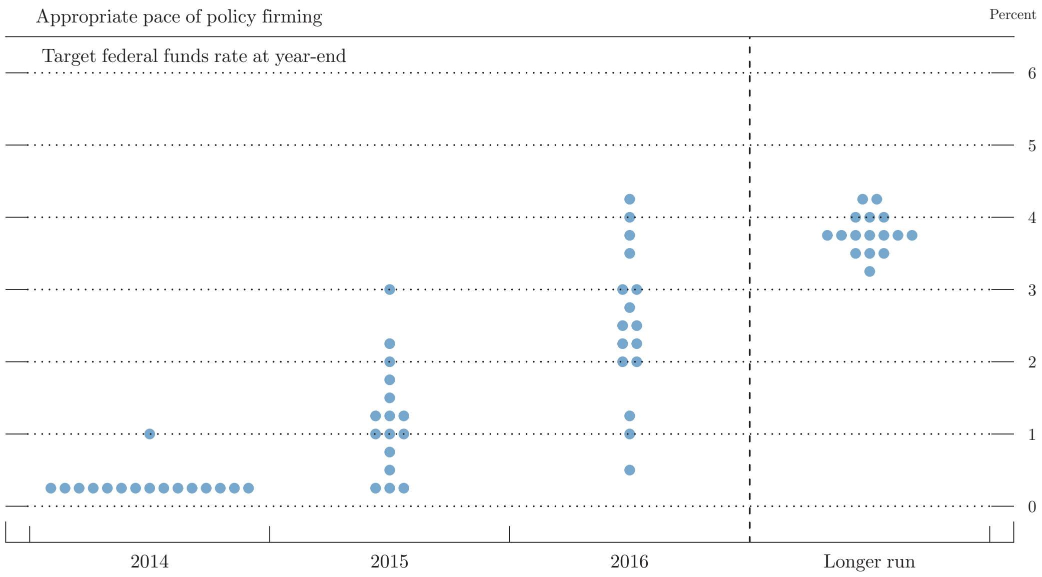

Figure 1.1: FOMC Participants’ Assessments of Appropriate Monetary Policy - June 2014 Summary of Economic Projections

Using SEP information, we provide what we believe is a first assessment of the degree of Fed commitment at the ZLB. To that end, we rely on two DSGE models in which policy is subject to the ZLB to infer information about Fed behavior and quantify the uncertainty around interest rates forecasts. First, we conduct the exercise using the standard New Keynesian model of Eggertsson and Woodford (2003). We then rely on the Smets and Wouters (2007) model (henceforth SW) to perform a more quantitative exercise. In each case, we first use SEP dots to extract information about Fed behavior, and then quantify the uncertainty around interest rates forecasts going forward, under the assumption about Fed behavior that best fits their own views regarding appropriate policy, as implied by the Dots.

As a first step, for each SEP release, we calibrate versions of the models to obtain central interest rate forecasts under different assumptions about the degree of monetary policy commitment. We then assess which specification provides the best fit to the SEP dots for each release date. We use that specification to construct uncertainty bands around the model-implied interest rate forecasts. Hence, we use the model, together with SEP data, to assess the degree of commitment of the Fed at the ZLB and, given this degree of commitment, to forecast interest rates.

SEP interest rate forecasts exhibit considerable dispersion, indicating that committee members have different opinions regarding the course of monetary policy. This might reflect differences in their assessment of the economic outlook – which are apparent in the SEP summary of participants' forecasts of unemployment, GDP growth and inflation – and/or different views about what the appropriate monetary policy is. In this paper, we abstract from such differences of opinion and focus on modeling central moments of the SEP dots. In the end, future interest rate decisions will amount to a single number (or range) for the policy rate at any time in the future, and this will be the outcome of some aggregation of the different views that participants might still hold about the appropriate policy rate for that point in time.

Our experiment assumes that at some date $t = 0$ (which we take to be the fourth quarter of 2008 – 2008Q4) the economy is hit by a deflationary shock, and the monetary authority responds by setting the target rate at zero. In the standard New Keynesian model, this is a shock to the discount factor that affects the natural interest rate. In the SW model the deflationary shock drives a wedge between the policy rate and the return on assets held by households.

We use the standard New Keynesian model to highlight the distinctive implications of different degrees of commitment for interest rate forecasts when at the ZLB. In this model it is straightforward to characterize the commitment and discretion solutions. We allow for three different types of Fed behavior: discretion, full commitment, and "partial commitment". The case of discretion consists of solving the optimal policy problem every period. In the standard commitment case, the Fed credibly commits, in 2008Q4, to a state-contingent plan for the target rate, which is followed forever. Finally, the case that we label "partial commitment" assumes that at each SEP date, the FOMC re-optimizes and ties itself to a new contingent plan. However, neither the Federal Reserve nor the public internalize *a priori* that this re-optimization will occur. So, at each SEP date, committee members report a future path for the policy rate assuming full commitment from that date onward. Under this scheme, the Fed reports a commitment trajectory, but its true behavior is quite discretionary: it reneges on the proposed commitment plan every time FOMC participants are asked to report new forecasts for the target rate.[2]

Although useful to illustrate the stark implications for future policy of

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[2] This is a simple way to depart from full commitment or discretion. Schaumburg and Tambalotti (2007) study the welfare gains from monetary policy commitment in a model of "quasi-commitment" that nests those two polar cases. Bodenstein et al. (2012) analyze optimal policy under imperfect commitment at the ZLB.

different degrees of commitment, the standard New Keynesian model is quantitatively unrealistic. Hence, for our quantitative exercise we turn to the SW model. Motivated by the results in Woodford (1999), we interpret highly inertial interest rate rules as indicative of a high degree of commitment.[3] This is justified, since a high interest-rate smoothing coefficient increases the time-dependence of the monetary policy rule, which is the main feature of monetary policy under commitment. Symmetrically, a small interest-smoothing coefficient implies little policy time-dependence, which is the essence of discretion.

Our results show that the degree of Fed commitment has decreased recently. Through the lens of the standard New Keynesian model, we find that partial commitment is the behavior which best describes SEP dots for all SEP dates except September 2014 when the best fit is discretion. In the SW model, we document a clear drop in the degree of policy inertia inferred from the last three SEPs, which we interpret as a decrease in the degree of commitment. In particular, the smoothing coefficient that best fits the September 2014 SEP projections is essentially zero, whereas the best-fitting coefficient for December 2014 is around 0.5. Therefore, the results from both models are similar.

Quantitatively, our median interest rate forecast from the SW model as of December 2014 implies that the lift-off will occur in 2015Q3. However, the uncertainty bands indicate a reasonable probability that the policy rate will remain at zero until 2016Q3.

Our paper fits in the literature seeking to characterize the Federal Reserve behavior in general, i.e., away from the ZLB. Since Taylor (1993) a vast number of papers seek to estimate a monetary policy rule that can account for variations in the Federal Funds rate[4]. There is also a large literature which focuses on estimating central bank's preference parameters[5]. However, these papers assume a specific type of policy behavior by the Federal Reserve: either a Taylor-type rule, commitment or discretion. Our analysis does not wish to make such assumption.

Even though forward guidance is all about commitment, there is not much empirical evidence in favor of a strict-committing Federal Reserve. Givens (2012) infers which policy behavior best fits US data: commitment or discretion. Under each of those two assumptions, he jointly estimates the structural parameters of the economy and the monetary authority's loss function parameters in a New Keynesian model. A comparison of model-generated moments with U.S. data for the 1982-2008 period favors the model under policy discretion.

[3] See also Nakov (2008) and Billi (2013).

[4] See, for example, Clarida et al. (2000), Taylor (2012) and the references therein.

[5] Examples are Favero and Rovelli (2003), Dennis (2004), Salemi (2006) and Ilbas (2012).

With respect to interest rate forecast at the ZLB, Bauer and Rudebusch (2013) is the paper which is closest to ours. Their goal is to extract expectations about monetary policy from the yield curve, explicitly taking into account the asymmetry induced by the ZLB. They use their estimated model to characterize the whole probability distribution of the policy rate and construct interval forecasts. Their modal projection for the lift-off is September 2015, which is close to ours.

Our paper is novel in a few dimensions: to the best of our knowledge, this is the first paper to infer policy behavior at the ZLB. It is also the first to use SEP dots data. The use of such data has a clear appeal: it directly reflects the views of FOMC members regarding appropriate monetary policy. They are, after all, the ones voting for monetary policy decisions.

This paper proceed as follows. Section 2 briefly outlines both models and explains how we characterize optimal monetary policy. Section 3 details our methodology – in particular, how we model the lift-off, calibration, solutions method and filtering procedure. Sections 4 and 5 discuss our results. Finally, Section 6 concludes.

2
Models and Monetary Policy

In this section, we describe both models and specify monetary policy conduction.

2.1
The Standard New Keynesian Model

The first model we use, is a textbook New Keynesian model subject to the zero lower bound. Our approach closely follows Eggertsson and Woodford (2003). The representative household chooses consumption, leisure, money and bond holdings to maximizes its additive separable utility function subject to a budget constraint. Firms operate under monopolistic competition and prices are sticky following Calvo (1983). There is a lower bound for the nominal interest rate, which arises from the household's money demand function. There are no real frictions. The only rigidity is on nominal prices.

For convenience, we skip the derivation of the model and present the familiar log-linear equations that we need: the inter-temporal IS curve and the New Keynesian Phillips Curve (NKPC). The reader can refer to Eggertsson and Woodford (2003) and Woodford(2003) for the complete derivation.

The inter-temporal IS curve and the New Keynesian Phillips Curve are given by:

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

$$\pi_t = \kappa x_t + \beta E_t \pi_{t+1} \tag{2-2}$$

where, x_t is the output gap: the percentage deviation of output from its natural (flexible prices) counterpart[1]; π_t is the inflation rate; r_t is the (nominal) target interest rate, controlled by the Federal Reserve; and r_t^n is the natural interest rate: the real rate of interest that prevails in equilibrium when $x_t = 0$; σ is the inter-temporal elasticity of substitution of consumption; κ is a positive parameter describing how inflation responds to variations in the current output gap; and β is the discount factor.

The only exogenous shock to the system comes from the natural rate of interest. In what follows, we will assume that such rate of interest is completely

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[1] If we define y_t as actual output, and y_t^n as natural output, then, $x_t = y_t - y_t^n$.

exogenous. In practical terms, a shock to the natural rate can be rationalized as a discount factor shock, since the steady-state level of this rate is $1/\beta$.

2.2
The Optimal Monetary Policy Problem in the Standard New Keynesian Model

With the system of equations that restrict the equilibrium, we define the optimal policy problem. We do this in a linear quadratic framework, following Eggertsson and Woodford (2003). It is standard in the literature two possible central bank behaviors: full commitment and discretion. We will also model an intermediate case, which we label as partial commitment. Under full commitment, the Federal Reserve ties itself to a state-contingent plan in 2008Q4, the date the economy was hit by the discount factor shock. The SEP dots reported under full commitment would be future values for the target rate under this very same contingent plan. Under partial commitment, however, the Fed changes its optimal plan every date when the SEP is released, naively projecting that it will be kept in future periods. Hence, under this behavior, the dots reported in June 2012 do not reflect the same contingent plan as the dots in June 2013, for example. But, conditional on the state of the economy, the solution for any given period after optimization is the same for partial or full commitment. Therefore, the solution for partial commitment is the same as full commitment. The only difference is the optimization date. Under discretion, the Central Bank is unable to commit to future policy and re-optimizes every period. It therefore chooses π_t and x_t at each point in time.

The optimal problem consists of minimizing the following loss function:

$$E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left[\pi_t^2 + \lambda x_t^2 \right] \right\} \tag{2-3}$$

subject to (2-1), (2-2) and a non-negativity constraint on the nominal interest rate, $r_t \geq 0$. The parameter $\lambda = \kappa/\beta$ represents the relative weight given by the Federal Reserve to output stabilization *vis-a-vis* inflation stabilization. The introduction of the zero lower bound condition makes the problem somewhat more complicated to solve. Jung et al. (2005) were the first to tackle this issue.

2.2.1
Discretion

As shown in Jung et al. (2005) the first order conditions are respectively given by:

$$\pi_t + \varphi_{2t} = 0 \tag{2-4}$$

$$\lambda x_t + \varphi_{1t} - \kappa\varphi_{2t} = 0 \tag{2-5}$$

$$r_t\varphi_{1t} = 0 \tag{2-6}$$

$$r_t \geq 0 \tag{2-7}$$

$$\varphi_{1t} \geq 0 \tag{2-8}$$

Equations (2-6), (2-7) and (2-8) are the Kuhn-Tucker conditions regarding the non-negativity constraint of the target interest rate. φ_{1t} and φ_{2t} are the Lagrange multipliers.

2.2.2
Full and partial commitment

In the case of commitment (both full and partial), the Central Bank solves the problem by choosing the entire sequence $\{\pi_t, x_t\}_{t=0}^{\infty}$. The first order conditions are:

$$\pi_t - \beta^{-1}\sigma\varphi_{1t-1} + \varphi_{2t} - \varphi_{2t-1} = 0 \tag{2-9}$$

$$\lambda x_t + \varphi_{1t} - \beta^{-1}\varphi_{1t-1} - \kappa\varphi_{2t} = 0 \tag{2-10}$$

together with (2-6), (2-7) and (2-8).

The first-order conditions show that the commitment solution is history dependent whereas the discretion solution is not. This is important, because, as Eggertsson and Woodford (2003) show, the optimal commitment policy prescribes that the policy-maker should promise to generate a positive output gap and inflation in the future (once the shock is over). This, in turn, means that the target interest rate should be held at the zero lower bound for an extended period *after* the shock has left the system. Such compromise will create positive inflation expectations, lowering the real rate of return and stimulating aggregate demand when the economy is still in the liquidity trap. That is, the central bank exchanges more inflation in the future for less deflation when the shock hits, improving the output-inflation trade-off. This is not true under discretion, in which case optimal policy requires the policy-maker to raise interest rates as soon as the shock has vanished.

2.3

The Smets and Wouters (2007) model

The Smets and Wouters (2007) model is a workhorse medium-sized DSGE model for the US economy. It includes both nominal and real rigidities. Our goal here is to summarize the model. There are four agents in this economy: households, firms, a fiscal authority and the Central Bank. We present the first three and leave the latter for the monetary policy discussion.

Households maximize their utility function that depends both on consumption (with habit formation) and labor. Households can rent capital services to firms and decide how much capital to accumulate. Capital accumulation is subject to adjustment costs, and capital utilization is variable. Households consume a basket of differentiated goods produced by the firms, which are aggregated using the Kimball (1995) aggregation, allowing for time-varying demand elasticity. Households can also buy bonds that yield a return rate (r^b) which is different from the target interest rate controlled by the Central Bank (r).

There is, therefore, a wedge between these two interest rates. As Smets and Wouters (2007) argue in their appendix, this wedge can be rationalized as a financial friction, and a shock to this wedge can be either interpreted as a risk premium shock or a financial shock. For our purposes, we will stick to the latter interpretation. A bad realization of this shock will lead the economy to the ZLB.

The households equilibrium relations are given by the Euler consumption equation (2-11); the Euler investment equation (2-12); and an arbitrage condition for the value of capital (2-13). All variables are log-linearized around their balanced growth steady-state:

$$c_t = c_1 c_{t-1} + (1 - c_1) E_t c_{t+1} + c_2 (l_t - E_t l_{t+1}) - c_3 \left(r_t - E_t \pi_{t+1} + \varepsilon_t^b\right) \tag{2-11}$$

$$i_t = i_1 i_{t-1} + (1 - i_1) E_t i_{t+1} + i_2 q_t + \varepsilon_t^i \tag{2-12}$$

$$q_t = q_1 E_t q_{t+1} + (1 - q_1) E_t r_{t+1}^k - \left(r_t - E_t \pi_{t+1} + \varepsilon_t^b\right) \tag{2-13}$$

where, c_t is consumption; l_t is the number of hours worked; r_t is the nominal target rate; π_t is the inflation rate; i_t is investment; q_t is the real value of capital stock; r_t^k is the real rental rate on capital. Finally, ε_t^b is the financial friction (or interest rate wedge / risk premium); and ε_t^i represents a disturbance to the investment-specific technology process. These two frictions are modeled as AR(1) processes with normal IID disturbances:

$$\varepsilon_t^b = \rho_b \varepsilon_{t-1}^b + \eta_t^b \tag{2-14}$$

$$\varepsilon_t^i = \rho_i \varepsilon_{t-1}^i + \eta_t^i \tag{2-15}$$

Our financial shock is given by the term η_t^b.

Firms operate under monopolistic competition, producing differentiated goods. Their production technology features labor-augmenting productivity and fixed costs. They borrow capital and labor services from households. Prices and wages are sticky and are set à la Calvo (1983). Prices and/or wages that are not re-optimized in a given period are partially indexed to past inflation.

The supply-side equilibrium relations are given by the aggregate production function (2-16); the law of motion of installed capital (2-17); the price-markup equation (2-18); the New Keynesian Phillips Curve (2-19); the wage-markup equation (2-20); the wage Phillips Curve (2-21); the relations between capital services and installed capital (2-22) - (2-23); and a cost minimization equation (2-24).

$$y_t = \phi_p \left(\alpha k_t^s + (1-\alpha) l_t + \varepsilon_t^a\right) \tag{2-16}$$

$$k_t = k_1 k_{t-1} + (1-k_1) i_t + k_2 \varepsilon_t^i \tag{2-17}$$

$$\mu_t^p = \alpha \left(k_t^s - l_t\right) + \varepsilon_t^a - w_t \tag{2-18}$$

$$\pi_t = \pi_1 \pi_{t-1} + \pi_2 E_t \pi_{t+1} - \pi_3 \mu_t^p + \varepsilon_t^p \tag{2-19}$$

$$\mu_t^w = w_t - \left(\sigma_l l_t + \lambda_1 \left(c_t - \lambda_2 c_{t-1}\right)\right) \tag{2-20}$$

$$w_t = w_1 w_{t-1} + (1-w_1)\left(E_t w_{t+1} + E_t \pi_{t+1}\right) - w_2 \Delta\pi_t - w_3 \mu_t^w + \varepsilon_t^w \tag{2-21}$$

$$k_t^s = k_{t-1} + z_t \tag{2-22}$$

$$z_t = z_1 r_t^k \tag{2-23}$$

$$r_t^k = -\left(k_t - l_t\right) + w_t \tag{2-24}$$

where, y_t is output; k_t^s is capital services; k_t is installed capital; z_t is the degree of capital utilization; μ_t^p is the price markup; μ_t^w is the wage markup; w_t is the wage rate; ε_t^a is total factor productivity, which is modeled as an AR(1), see (2-25); ε_t^p is a price markup disturbance; and ε_t^w is a wage markup disturbance; These last two are assumed to follow ARMA(1,1) processes, see (2-26) - (2-27).

$$\varepsilon_t^a = \rho_a \varepsilon_{t-1}^a + \eta_t^a \tag{2-25}$$

$$\varepsilon_t^p = \rho_p \varepsilon_{t-1}^p + \eta_t^p - \mu_p \eta_{t-1}^p \tag{2-26}$$

$$\varepsilon_t^w = \rho_w \varepsilon_{t-1}^w + \eta_t^w - \mu_w \eta_{t-1}^w \tag{2-27}$$

There is also an aggregate resource constraint (2-28), given by:

$$y_t = c_y c_t + i_y i_t + z_y z_t + \varepsilon_t^g \tag{2-28}$$

where, ε_t^g is the exogenous government spending term, which follows an AR(1) with a normal IID innovation (2-29).

$$\varepsilon_t^g = \rho_g \varepsilon_{t-1}^g + \eta_t^g \tag{2-29}$$

2.4
Monetary Policy in the Smets and Wouters (2007) model

While the SW model is more realistic with frictions and endogenous states, this realism does not come at no cost. Solving for the optimal discretion and commitment policies in this model is not straightforward. The interaction of the endogenous states with the zero lower bound (which, in turn, affects current expectations) renders the task computationally extremely challenging. In this paper, we provide an alternative solution which we believe shares the same insights of the fully optimal solution. More specifically, although we do not characterize the actual discretion and commitment solutions, our procedure enables us to assert if the time dependence of monetary policy, which is a characteristic of optimal policy, has changed.

As in the SW model, we assume monetary policy is given by the following Taylor Rule:

$$r_t = \rho r_{t-1} + (1-\rho)\left[\phi_\pi \pi_t + \phi_y \left(y_t - y_t^p\right)\right] + \phi_{\Delta_y}\left[\Delta\left(y_t - y_t^p\right)\right] + \varepsilon_t^r \tag{2-30}$$

where, ε_t^r is a monetary policy shock, that follows an AR(1) process; and y_t^p is potential output.

$$\varepsilon_t^r = \rho_r \varepsilon_{t-1}^r + \eta_t^r \tag{2-31}$$

Equation (2-30) implies that the Central Bank *gradually* adjusts the target rate, r_t, in response to inflation and the output gap. The last term represents a feedback response from changes in the output gap.

The parameter $\rho \in [0,1)$ represents the interest rate smoothing coefficient and, thus, it determines the degree of inertia or time-dependence of monetary policy. If ρ is close to 1, the Taylor Rule is very time-dependent, as future movements of the target rate are strongly correlated with the the lagged state of the economy (collected in r_{t-1}). We also know that commitment exhibits far more time-dependence than discretion. The latter, in fact, is not a time dependent policy, as the Central Bank is assumed to re-optimize every period. Therefore, it is intuitive that if the interest rate smoothing coefficient is close to one, the rule given by (2-30) will implement a solution that is closer to commitment. Symmetrically, if $\rho \approx 0$, the Taylor rule will be closer to the discretion solution.

Our argument is supported by some results available in the literature. Woodford (1999) shows that optimal commitment policy displays intrinsic inertia in interest-rates responses, in a standard New Keynesian model without the zero lower bound. He also demonstrates that a Taylor Rule with a high enough interest rate smoothing coefficient can implement a solution that is close to the optimal commitment.

In a more similar context to ours, Nakov (2008) studies which simple policy rule best replicates the optimal commitment policy in a standard New Keynesian model with the zero lower bound. He finds that when there is a liquidity trap possibility, a Taylor Rule that controls the first-difference of the target rate (which is equivalent to an unitary smoothing coefficient) is the one which best replicates the outcome under commitment.

In a recent working paper, Billi (2013) argues that $\rho = 1$ is an indication that the Central Bank gives forward-guidance on the target rate level and, if this is the case, inflation is more tightly anchored.

On the empirical side, Givens (2012) reports that under discretion, interest-rate smoothing is the most important objective in the Federal Reserve's loss function, whereas under discretion, it is the least important.

These results gives us confidence that modeling the types of monetary policy using this strategy reproduces the main issues in the discretion and commitment policies.

3
Solution and Simulation

In this section we describe the solution method we use for DSGE models with inequality constraints. Then, we explain the filtering problem associated with the SW model. Finally, we explain how we model the exit from the ZLB and discuss calibration.

3.1
Solution Method

The model cannot be solved using standard perturbation methods, because of the non-linearity introduced by the zero lower bound. We use a piece-wise linear solution method for both models. This method was first proposed in Jung et al. (2005) for a deterministic context. Eggertsson and Woodford (2003) generalized the algorithm for a stochastic context in which the natural interest rate can only take two values, and one is an absorbing state. Finally, Guerrieri and Iacoviello (2014) extended the solution method for general processes, and developed a toolkit that implements it, OccBin. We use this toolkit in our paper.

The intuition of the solution method is to combine the impulse response functions of two different regimes: one regime in which the constraint is never binding (3-1) and one in which the constraint is always binding, equation (3-2):

$$\mathcal{A}E_tX_{t+1} + \mathcal{B}X_t + \mathcal{C}X_{t-1} + \mathcal{E}\varepsilon_t = 0 \tag{3-1}$$

$$\mathcal{A}^*E_tX_{t+1} + \mathcal{B}^*X_t + \mathcal{C}^*X_{t-1} + D^* + \mathcal{E}^*\varepsilon_t = 0 \tag{3-2}$$

where, X_t is a vector of endogenous variables, ε_t is a vector of shocks and D^* is a vector which arises because linearization is carried out around the steady-state of (3-1).

Given an initial condition X_0 and the realization of a shock ε_1, the algorithm is based on a simple guess-and-verify approach. First, guess that regime (3-2) starts in τ_1 and ends in τ_2. Then, assuming (3-1) satisfies the Blanchard and Kahn (1980) conditions, the solution for $t > \tau_2$ is given by:

$$X_t = \mathcal{P}X_{t-1} + \mathcal{Q}\varepsilon_t \tag{3-3}$$

Now, assuming no other shocks are expected, we know from (3-3) that $E_{\tau_2}X_{\tau_2+1} = \mathcal{P}X_{\tau_2}$. Substitute this into (3-2) to obtain, for τ_2:

$$\mathcal{A}^*\mathcal{P}X_{\tau_2} + \mathcal{B}^*X_{\tau_2} + \mathcal{C}^*X_{\tau_2-1} + D^* = 0$$

After re-arranging we obtain the decision rule for X_{τ_2} given X_{τ_2-1}:

$$X_{\tau_2} = \mathcal{P}_{\tau_2}X_{\tau_2-1} + \mathcal{R}_{\tau_2} \tag{3-4}$$

where, $\mathcal{P}_{\tau_2} = -(\mathcal{A}^*\mathcal{P} + \mathcal{B}^*)^{-1}\mathcal{C}^*$ and $\mathcal{R}_{\tau_2} = -(\mathcal{A}^*\mathcal{P} + \mathcal{B}^*)^{-1}\mathcal{D}^*$.

Iterate backwards in the same fashion until X_0 is reached, applying regime (3-2) for $\tau_1 < t < \tau_2$ and regime (3-1) for $t < \tau_1$. For period $t = 1$, the solution will have the form:

$$X_1 = \mathcal{P}_1X_0 + \mathcal{R}_1 + \mathcal{Q}_1\varepsilon_1 \tag{3-5}$$

where, $\mathcal{Q}_1 = -(\mathcal{A}^*\mathcal{P}_2 + \mathcal{B}^*)^{-1}\mathcal{E}$. After that, the path for X_t can be simulated and the guess for the regimes duration can be verified.

The most striking advantage of the piece-wise linear solution method is its computational speed. Since it is basically an interpolation of impulse response functions solved using perturbation methods, it is much faster than global solution methods. Also, the solution using the piece-wise method can be highly non-linear. The dynamics may be affected by how long the constraint is expected to be binding.

3.2
Filtering the State of the Economy

The SW model features endogenous states. In terms of the solution method described earlier, the SW model requires knowledge of the state of the economy to form the initial vector X_0.

As a result, we need a filtering algorithm to obtain this information. Generally, we can write the solution of the model as:

$$X_t = \mathcal{P}\left(X_{t-1}, \varepsilon_t\right) X_{t-1} + \mathcal{D}\left(X_{t-1}, \varepsilon_t\right) + \mathcal{Q}\left(X_{t-1}, \varepsilon_t\right) \varepsilon_t \tag{3-6}$$

If we have a vector of observed time-series Y_t, we know there is a selection matrix $\mathbf{H}$ so that: $Y_t = \mathbf{H}X_t$. Therefore, (3-6) can be expressed as:

$$Y_t = \mathbf{H}\mathcal{P}\left(X_{t-1}, \varepsilon_t\right) X_{t-1} + \mathbf{H}\mathcal{D}\left(X_{t-1}, \varepsilon_t\right) + \mathbf{H}\mathcal{Q}\left(X_{t-1}, \varepsilon_t\right) \varepsilon_t \tag{3-7}$$

Equation (3-7) is equivalent to a state-space representation of linear models. It means we can recursively solve for ε_t given the last state X_{t-1} and current data Y_t. However, since the coefficients on the solution form (3-6) - (3-7) have endogenous variations (ie, they depend on ε_t and X_{t-1}) we cannot use the Kalman Filter.

Instead we use an algorithm inspired by Guerrieri and Iacoviello (2013). The intuition is as follows: given an initialization for the state vector X_0, search for the vector of shocks that minimizes the distance between simulated and observed data in period $t = 1$. Then, using the filtered state X_1^f, repeat the exercise for $t = 2$, and so on. A complete description of the algorithm is given below.

Given an initial value for the state vector X_0, guess a vector of shocks ε_1 (Guess 1), then guess a duration for the zero lower bound (Guess 2). Using Guess 1 and Guess 2, solve the model and simulate the trajectory for the filtered endogenous variables, X_1^f. Construct a simulated vector of observables: $Y_1^f = \mathbf{H}X_1^f$. Verify the duration of the ZLB (Guess 1). Verify if the distance between the simulated data (Y_1^f) and real data (Y_1) is small enough. Repeat for all t.

In the SW model, the vector of data Y_t is composed of seven variables: log difference of real GDP; real consumption; real investment; log difference of the GDP deflator; real wage; log of hours worked; and the federal funds rate. The data are collected from the same sources as Smets and Wouters (2007) and are treated as described in their appendix. All data are quarterly and the sample is 1985Q1 to 2014Q2, consisting of 118 observations. We use the first 25 observations as a training sample (1985Q1 - 1991Q1).

The filtering problem is not a concern when dealing with the standard New Keynesian model. Because of the forward looking nature of the model there are no endogenous states. Therefore, we can solve for 2008Q4 onward assuming that the economy was at the steady-state before the shock.

3.3
Modeling the exit from the ZLB

Solving the model with the OccBin toolkit requires a sequence of shocks as an input. Therefore, we need to assign some kind of stochastic process to model the exit from the zero lower bound. We assume the financial shock (or the discount factor shock in the case of the basic New Keynesian model) has a constant probability of exiting the economy every period. In this section, we describe how we compute the path for the target interest rate.

In the standard New Keynesian Model, we assume that at date t_0 the economy is hit by a shock which makes the natural interest rate suddenly negative ($r_t^n = r_L < 0$). This shock has a constant probability γ of disappearing every period. Once the shock is gone, the natural interest rate reverts back to its steady state level and there it stays ($r_t^n = r_H > 0$). The natural rate, therefore, can take only two values, and its steady state is an absorbing one.

The date τ at which the shock is over is a random variable.

As shown in Eggertsson and Woodford (2003), optimal policy prescribes that the target rate should be kept at the zero lower bound for an additional number of periods – k – after the shock is not present (in the case of discretion, $k = 0$). Therefore, there will be a period of time when the economy will not be affected by the shock, but interest rates will still be zero.[1]

Thus, the experiment can be thought of as having three stages: in the first stage, the shock is present and the zero lower bound is binding ($t_0 \leq t < \tau$); in the second stage the shock is absent but the zero bound is still active ($\tau \leq t \leq \tau + k$); and in the third stage, the shock is absent and the target interest rate is positive ($t > \tau + k$). This should not be confused with the two regimes described in section 3.1. Regime (3-2) applies to stages 1 and 2, whereas regime (3-1) applies to stage 3.

How can we use this experiment to test if the Federal Reserve members are forecasting the target rates with discretionary, fully committed, or partially committed policies in mind? Suppose we are interested in analyzing the FOMC behavior in period T, a date in which the target rate projections in the SEP are released. We need to compute, for each of the three possible behaviors, the future path of the fed funds rate from T onward.

For a given policy behavior, we solve the model for a number of different contingencies, each of which representing a particular history for the shock process. These histories are indexed by the period in which the shock is undone: the j-th contingency, corresponds to the case in which the discount factor shock reverses in the j-th period. Given the stochastic nature of the shock process, the probability of observing such a history is $\gamma\,(1-\gamma)^{j-1}$.

Therefore, for a given time period, we obtain the whole probability distribution of the target rate. So, after solving the model for several shock contingencies, we compute the weighted average for all variables in every time period.

Why do we aggregate contingencies using a weighted average and not the median or mode? Because of the stylized nature of the basic New Keynesian model, the optimal policy recommendation is to increase the target rate to the steady-state value all at once, when lift-off begins. Therefore, the target rate almost always takes on only two values: zero and the steady-state level. If we used the median or mode, the simulated trajectory would preserve this feature, which is definitely different from the SEP dots. By using the weighted-average we can obtain a more smooth trajectory. For the SW model, the smoothness

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[1] Formally, we define k as the smallest integer such that at time $\tau + k + 1$ the target rate is greater than zero.

arises endogenously from the model, so we can aggregate the trajectories using the median.

The date t_0, when the shock first appears, corresponds to the fourth quarter of 2008 (2008Q4). In date T, when the SEP projections are released, there are some simulated contingencies for which the shock has already reversed to its normal value, and in such contingencies optimal policy may prescribe a positive value for the nominal interest rate. We know, however, that the zero lower bound is still binding in T, as the FOMC has not yet increased the fed funds rate. Therefore, in the weighted average calculations, we exclude all the contingencies for which the natural rate has returned to its steady state level prior to T.

Having computed the future path of the target rate for all three possible behaviors, we compare each one of them with the median SEP dots, released in date T. We calculate the euclidean distance between the simulated path and the FOMC median projection for every future quarter in which a projection exists. The simulated path with the minimum sum of distances to the real SEP data is the one which best describes the committee's policy conduct at date T. We repeat this exercise for all dates when the SEP was released, to check if there have been changes in the FOMC behavior through time.

Once we have established the most likely policy conduct by the FOMC, we can quantify the uncertainty with respect to the timing of the fed funds rate lift-off. Since we do not have only a central moment of the target rate, but rather the whole probability distribution, we can look at percentiles to assess uncertainty.

The procedure for the SW model is similar. However, as described earlier, we model monetary policy differently. We also need to filter the state of the economy before projecting the interest rates. In this section, we outline the steps in order to forecast policy rates in this model.

For a given SEP, we filter the state of the economy up to the projections release date. Then, we search for the best-fitting smoothing coefficient of the Taylor Rule by solving and simulating our model repeatedly, for all ρ values in a grid between 0 and 1 with size 0.01.

For a given smoothing coefficient, we simulate from the SEP date T onward, drawing several contingencies for the financial shock history. Our baseline specification uses the same stochastic structure as the discount factor shock in the standard New Keynesian model (ie, the shock has a probability γ of exiting the economy in a given period). Therefore, for a given time period we characterize the probability distribution of the target rate.

Then, we aggregate all simulations by the median, and compute the distance between the median simulated target rate path and the median reported SEP dots. We repeat this exercise for all values that the smoothing coefficient can take in the grid. The one which yields the closest simulated trajectory to the SEP dots is the “true” coefficient of the Taylor Rule for that SEP date. The value of the smoothing parameter, in turn, indicates the degree of time-dependence or inertia of monetary policy.

Once we have characterized the policy behavior by the FOMC, we can quantify the uncertainty surrounding the lift-off timing. Similar to the standard New Keynesian model, we compute the 10th and 90th percentiles of the simulated probability distribution for the target rate under the best-fitting smoothing coefficient.

Different from the standard New Keynesian, the SW model has seven shocks. The stochastic structure attributed to the financial shock is not shared by the other shocks. There are, however, a few possibilities to model these other innovations. Our preferred specification is to allow all other innovations to be drawn from an IID normal distribution with zero mean and constant variance. We calibrate the variance according to the estimation in Smets and Wouters (2007).

We also experiment with different set-ups. We consider the case where the only shock in the SW model is the financial one. This allows us to assess the impact of the financial friction directly. The shock structure is the same as in our baseline specification.

Lastly, when we use the filtering algorithm described in section 3.2, we obtain shocks that are correlated with each other and through time. This potentially points out a specification error in our model. To mitigate this, we also conduct the simulations after drawing all other innovations from a parsimonious VAR model estimated using the filtered shocks. The stochastic process for the financial shock is maintained. Results do not change.

3.4
Why aggregate SEP dots using the median?

At this point, a natural question is why do we aggregate the SEP dots using the median? As mentioned in the introduction, the differences of opinion between FOMC members compels us to aggregate the dots in some way.

The important point is that we do not know how voting takes place during FOMC meetings. If the FOMC were a pure democracy with secret voting, then the most likely outcome of policy tightening would be the opinion of the median member. However, we do not know if this is true. It could be the case that members wait until some sort of “super majority" is convinced

Table 3.1: Calibration of Structural Parameters

Parameter	Value	Target
Discount Factor β	0.995	SS level of target rate
Intertemp. Elasticity of Subst. σ	1.00	Literature
Goods Elasticity of Subst. θ	7.88	Literature
Response of Inflation to Gap κ	0.01	Inflation rate and output gap
Magnitude of shock r_L	-4.75%	for the US in 2009
Prob of Shock Reversal γ	Appendix A	Quarters from SEP until lift-off

and then voting is almost unanimous. This would require looking at a lower percentile of the distribution. Alternatively, if a few FOMC members (such as the chair) steer the decision and the rest follows along, then we should only focus on the dots of these "driver-members".

Since we are not sure if members follow the chair (and, of course, we are ignorant about who the dots are) or even if they wait for a super majority, we believe looking at the median is the most parsimonious assumption about the FOMC committee decision rules.

3.5
Calibration

For the standard New Keynesian model, we use standard values available in the literature. We assume a unitary elasticity of inter-temporal substitution[2], a discount factor of $\beta = 0.995$ and an elasticity of substitution of $\theta = 7.88$, following Rotemberg and Woodford (1997). Table 3.1 displays the calibrated parameters. We assume a steady-state level of inflation equal to 2% a year. Since the model has quarterly frequency, the discount factor of 0.995 and the long-run inflation imply that the steady state value of the nominal interest rate is 4% a year.

To calibrate the values of the NKPC parameter κ and the magnitude of the shock hitting the economy r_L, we run the model and try to find a combination of these two parameters that produce a path for inflation and the output gap that are consistent with US data for the year 2009. The year over year change in CPI was -0.4% and the output gap as a percentage of real gross domestic product was -7.15%. We find that the combination $\kappa = 0.01$ and $r_L = -4.75\%$ does a good job in replicating these numbers.

To obtain a value for the probability γ, one possibility is to look at the number of quarters from the SEP release-date until the target rate lift-off as implied by committee members' opinions. We know, however that the

[2] See, for example, Chari et al. (2000).

shock's exit probability is not the same as the lift-off probability, because of the endogenous monetary policy delay that arises under commitment.

To deal with this problem, we need to find a probability γ that will deliver an endogenous delay such that we observe the same lift-off as the one implied by SEP data. This fine tuning is not a difficult task. Basically, we start with an initial guess for the exit probability (based on the lift-off duration in the data) and search for values in the neighborhood of this starting point until we match the observed lift-off date. Since the detailed description of this procedure is somewhat cumbersome, we leave it to the Appendix.

It is important to stress that this probability changes according to the SEP date and also according to which type of policy behavior we are assuming.

The SW model has approximately 60 parameters, so we refrain from showing the calibrated values for all of them. The interested reader can refer to the original paper. We only highlight our changes in parameter values.

We calibrate the SW model using the mode of the estimated posterior distribution for most of the parameters. However, the estimation conducted in Smets and Wouters (2007) imply some unreasonable values for the steady-state. In particular, steady-state inflation, output growth and nominal interest rates are 3.24%, 1.72% and 6.30%, respectively.

Two parameters govern steady-state inflation and output growth directly, so we alter these to obtain 2% and 2.5%. These numbers are more aligned with FOMC members projections available in the SEP. Also, the long-run value for the target rate is approximately 4%, as reported by members. The steady-state level of the interest rate is influenced by the discount factor (β), the inter-temporal elasticity of consumption substitution (σ_c), and the steady-state level of inflation and output growth.

We calibrate the discount factor to $\beta = 0.9992$ and the inter-temporal elasticity to $\sigma_c = 1.16$. The estimated values were 0.9984 and 1.39, respectively. Our calibrated values are above the 5-th percentile of the estimated posterior distribution, as reported in Smets and Wouters (2007). These values, together with the calibration for the steady-state inflation and output growth, imply that the long-run level of the nominal interest rate is approximately 4%.

The magnitude of the financial innovation is the average of the filtered financial shock from 2008Q4 until the appropriate SEP release date. As for the other shocks, when assuming that they are drawn from a normal distribution with zero mean and constant variance, we use the estimated standard deviation available in Smets and Wouters (2007).

As for the exit probability γ, under the SW model, it would be computationally impossible to fine tune that probability as described earlier, since we are also simultaneously conducting a grid search for the best-fitting smoothing coefficient. Therefore, for the SW model we will simply use the starting point probability for which we conduct our fine tuning under the New Keynesian model (for details as how to obtain this initial guess, refer to Appendix A).

4
Results for the standard New Keynesian model

4.1
How has the FOMC been conducting monetary policy?

In this section we answer our main question: are the reported SEP dots better described by a discretionary or a committed Federal Reserve? Here we consider only the standard New Keynesian model.

Table 4.1 presents the sum of distances between the average reported target rate trajectories and the (weighted average of) simulated ones, organized by type of behavior and release date. The asterisk mark indicates the behavior which best fits the reported target rate trajectory in the specified release date.

According to Table 4.1, the policy that best describes the SEP dots for most dates is partial commitment. Under partial commitment, the Federal Reserve re-optimizes its contingent plan every time it releases new projections. Thus, its true behavior is quite discretionary.

Deviations from partial commitment are observed in three dates: in January 2012 and March 2013 there is a tie between partial and full commitment. This suggests that the degree of commitment in those particular dates might be high. However, in September 2014, the best-fitting type of policy is discretion.

In all, the commitment degree of the Federal Reserve has been imperfect throughout this period.

Figures 4.1 and 4.2 depict the average SEP dots and the average simulated path for the target rate under the type of policy which best fits the dots, respectively, in December 2013 and December 2014. Appendix 8.2 contains additional figures for the other SEP dates.

In December 2013 the projected interest rate path under discretion is significantly more hawkish that the reported SEP. In particular, it prescribes that the lift-off should take place during 2014. The trajectories under full and partial commitment, on the hand, closely track the dots in 2013Q4 and 2014Q4, implying a 2015 lift-off.

In December 2014, the projections under partial commitment perfectly fits the average reported dots (see Figure 4.2). The discretion trajectory is very steep, suggesting a rather extreme pace for monetary tightening. On the other hand, under full commitment the pace of tightening would be more cautions than what committee members were expecting as of December 2014.

Table 4.1: Distance Between Simulated and Reported (Average) Path for the Target Rate

Date of Projection Release	Discretion	Full Commitment	Partial Commitment
January 2012	5.13	0.13*	0.13*
April 2012	4.81	0.31	0.13*
June 2012	5.56	0.06	0.00*
September 2012	4.25	0.25	0.06*
December 2012	4.81	0.56	0.25*
March 2013	5.06	0.25*	0.25*
June 2013	4.75	0.25	0.06*
September 2013	3.75	1.06	0.06*
December 2013	4.38	2.50	1.81*
March 2014	4.38	3.31	1.63*
June 2014	3.19	2.88	1.31*
September 2014	2.19*	6.56	2.31
December 2014	3.56	2.25	0.06*

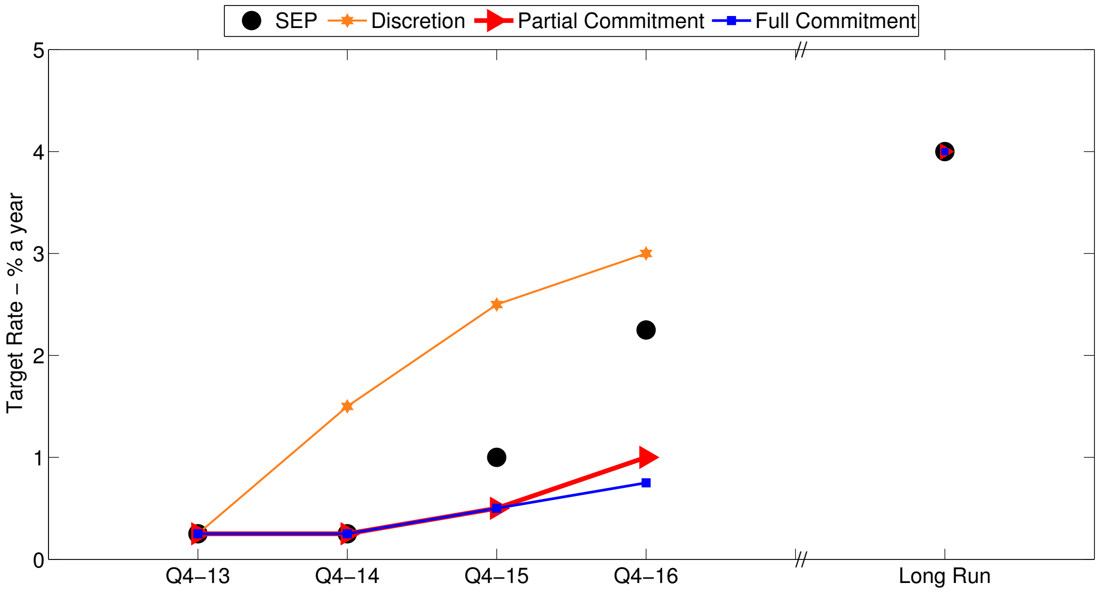

Figure 4.1: Reported and Simulated Paths for the Target Rate using the New Keynesian model - December 2013

Even though results in Table 4.1 suggest an imperfect degree of commitment for the FOMC members, the basic New Keynesian model does not allow us to make any further inference. We do not know, for example, if the degree of commitment was greater in December 2014 or in December 2013. On the other hand, the SW model can answer that, as the Taylor Rule strategy to model monetary policy gives us the needed flexibility.

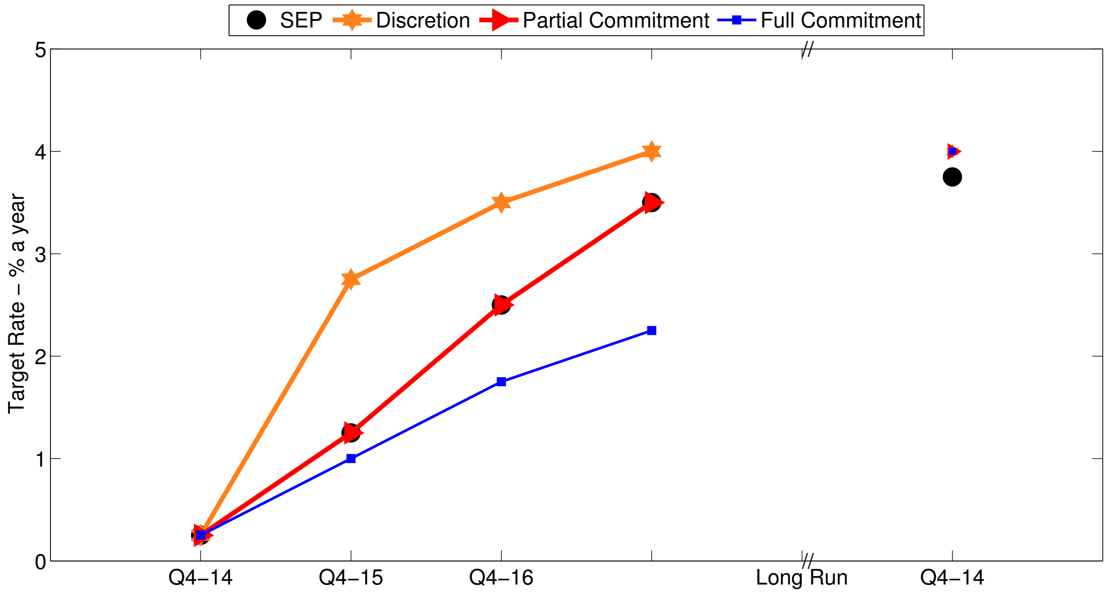

Figure 4.2: Reported and Simulated Paths for the Target Rate using the New Keynesian model - December 2014

4.2
When will the target rate lift-off?

Having established the most plausible policy conduct behavior by the Federal Reserve, we compute confidence intervals around our simulated trajectory for every SEP. These “uncertainty bands” correspond to the percentiles of the simulated target rate probability distribution for a given horizon. We report the 5th-95th, 10th-90th, 15-85th, 25th-75th and 35th-65th percentiles. Figure 4.3 shows the simulated weighted average path of the target rate, the confidence bands and the average reported September 2014 SEP dots for the 2014-2017 period. The lighter grey shades correspond to the 5th-95th pair of percentiles, while the darker grey to the 35th-65th percentiles.

Figure 4.3 has one striking feature: the confidence intervals are too wide. For example, the 35th-65th percentiles for 2015Q4 indicate that the target rate could be anywhere between 0.25% and 2.75%. Also, these same percentiles suggest the lift-off might take place during 2015 or even during 2017.

This is a setback of the basic New Keynesian model. In a purely forward looking setup with no real rigidity, optimal policy recommends that, once lift-off commences in a given contingency, the central bank should place the target rate at the steady-state level in a couple of sizable moves. This explains the pattern observed in Figure 4.3.

As for the lift-off uncertainty, the 35th-65th percentile pair indicates that the first rate increase might be as late as 2017Q2, or as early as 2015Q4.

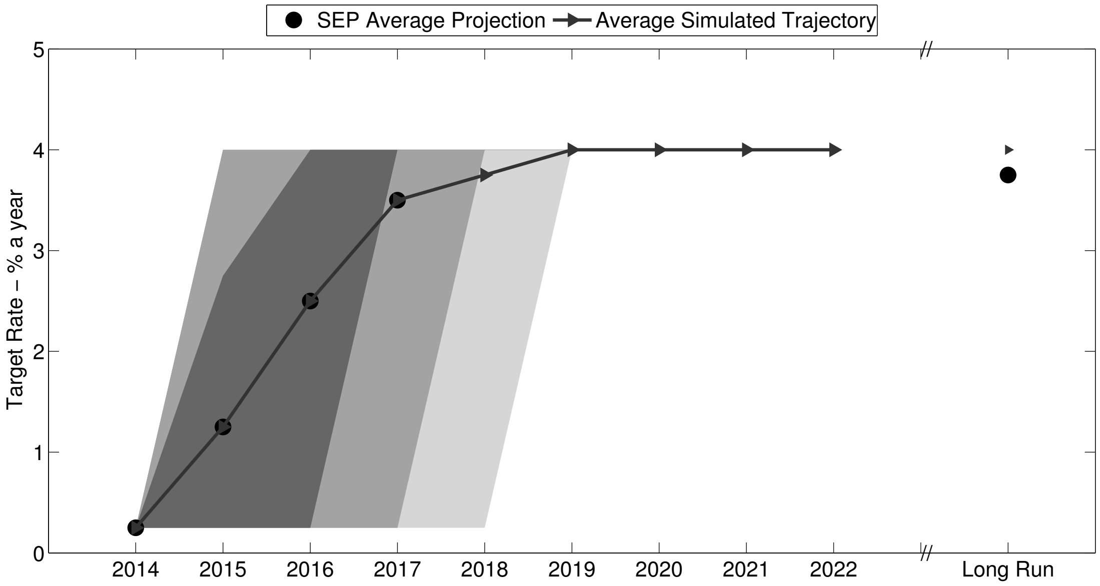

Figure 4.3: Reported, Simulated Path and Intervals for the Target Rate - December 2014

However, if we look at more extreme percentiles, the variability increases dramatically. The 5th-95th pair, for example, shows an early increase in 2015Q2 or a late increase only in 2019Q2.

These deficiencies justify the use of a more quantitative model such as SW, where rigidities, endogenous states and monetary policy smoothing turn the experiment more realistic.

5
Results for the Smets and Wouters (2007) model

5.1
How has the FOMC been conducting monetary policy?

Now, we report results for the SW model. First, we wish to characterize the bset-fitting interest rate smoothing coefficient, that is, the one which minimizes the distance between the median simulated interest rate trajectory and the median reported SEP dots. For the SW model, we do not need to use the weighted average simulation, as we did earlier. Table 5.1 shows the results for our preferred specification: the financial shock has the same two-state stochastic nature as before, and all remaining shocks are NID.

Table 5.1 indicates a clear change in policy behavior by the FOMC. Until December 2012, the SEP dots are consistent with a highly inertial monetary policy. The best-fitting smoothing coefficient ranges from 0.90 to 0.94, with an average of 0.92. The high values for the smoothing coefficient suggest the FOMC has been acting under commitment during 2012.

However, in 2013 and 2014 there is a downward shift in the intensity of monetary policy inertia. From March 2013 to March 2014 the average smoothing coefficient is 0.86, with a range from 0.80 to 0.91. And in the last three SEPs (Jun, September and December 2014) there is a more drastic reduction. The coefficient is 0.63, 0.06 and 0.44, respectively.

This result suggests that the degree of commitment by the FOMC has decreased. In fact, for the September 2014 SEP, the best-fitting smoothing coefficient is 0.06, meaning that the dots were projected assuming a Taylor Rule with almost no dependence to past states of the economy. This would characterize the behavior of the committee as discretionary.

In December, the commitment degree increased somewhat, but it remains well below the levels observed in 2012 and 2013.

Nonetheless, the computed distances for the September and December 2014 SEP are considerably greater than the other dates, indicating that even though the Taylor Rule with less inertia is the best fit for the dots, it performs poorly compared to the other SEP dates. This is a somewhat counter-intuitive result, as our experiment was designed to match the median dots. Note however, that if we turn-off the other NID shocks, the median trajectory tracks the dots somewhat closer.

Table 5.1: Best-fitting interest rate smoothing coefficient: Benchmark specification[a]

Date of Projection Release	Best-fitting Smoothing Coefficient ρ	Distance
January 2012	0.92	0.544
April 2012	0.92	0.119
June 2012	0.92	0.269
September 2012	0.90	0.280
December 2012	0.94	2.951
March 2013	0.88	0.072
June 2013	0.90	0.064
September 2013	0.80	0.134
December 2013	0.83	0.101
March 2014	0.91	0.106
June 2014	0.63	0.248
September 2014	0.06	3.629
December 2014	0.44	4.145

[a] Financial shock follows the stochastic two-state process with constant exit probability, and other shocks are NID.
NOTE: Simulations are conducted with 750 draws of shock sequences for each possible value of ρ. Grid considered is between 0.00 and 0.99, with 0.01 increases.

It is important to observe that the results using the SW model are in line with the New Keynesian model (see Table 4.1), that is, that the degree of monetary policy commitment has decreased during the 2012-2014 period. Also, the discretionary behavior by the Fed in September 2014 is captured by both models.

The reduction in policy inertia captured by our experiment follows a significant change in the FOMC forward guidance statement. Until December 2012, the FOMC used a time dependent framework in order to express forward guidance. For example, the statement in the June 2012 meeting read:

> "(...) the Committee decided today to keep the target range for the federal funds rate at 0 to 1/4 percent and currently anticipates that economic conditions–including low rates of resource utilization and a subdued outlook for inflation over the medium run–are likely to warrant exceptionally low levels for the federal funds rate at least through late 2014."

However, in December 2012 the committee decided to switch to a state dependent framework when expressing forward guidance. This change followed a recommendation made by Woodford (2012) in the Jackson Hole meeting. The December 2012 statement read:

> “(...) the Committee decided to keep the target range for the federal funds rate at 0 to 1/4 percent and currently anticipates that this exceptionally low range for the federal funds rate will be appropriate at least as long as the unemployment rate remains above 6-1/2 percent, inflation between one and two years ahead is projected to be no more than a half percentage point above the Committee’s 2 percent longer-run goal, and longer-term inflation expectations continue to be well anchored.”

The decrease in policy commitment only begins in 2013 (and accelerates in 2014), but it is still insightful to account that the change in guidance anticipated the reduction in commitment as captured by the Summary of Economic Projections dots.

In the end of 2013 the FOMC also announced the tapering of its Quantitative Easing program (QE). Starting in January 2014, the Federal Reserve would start adding mortgage-backed securities and Treasury securities to its balance sheet at slower paces. The QE eventually ended in October 2014.

As our results show, it is precisely in 2014 that the decrease in the best-fitting smoothing coefficient is clear-cut. Therefore, the more discretionary projections of the SEP are simultaneous to the QE tapering. This is somewhat intuitive: as the Federal Reserve alters its commitment to increase its balance sheet, it is expected that the FOMC members would start projecting the target rate using a more discretionary framework. Also, as the QE ended, the Fed continued showing reduced levels of commitment (as implied by the December 2014 SEP).

5.2
When will the target rate lift-off?

Finally, we address the lift-off in the more realistic SW model. Once again, we define the uncertainty bands as the percentiles of the simulated fed funds rate distribution. As in the New Keynesian model, we report the 5th-95th, 10th-90th, 15-85th, 25th-75th and 35th-65th percentiles. Figures 5.1 and 5.2 show the simulated median trajectory of the fed funds rate and the reported median SEP dots for December 2013 and December 2014, respectively.

Note that the SW model is able to track the SEP dots even when we aggregate the simulated path using the median. That is, we do not need to compute the weighted average, because the model itself delivers a smoother increase for the target rate.

However, for the December 2014 SEP it still seems that the SW model is having trouble matching the reported dots. Even though the best-fitting

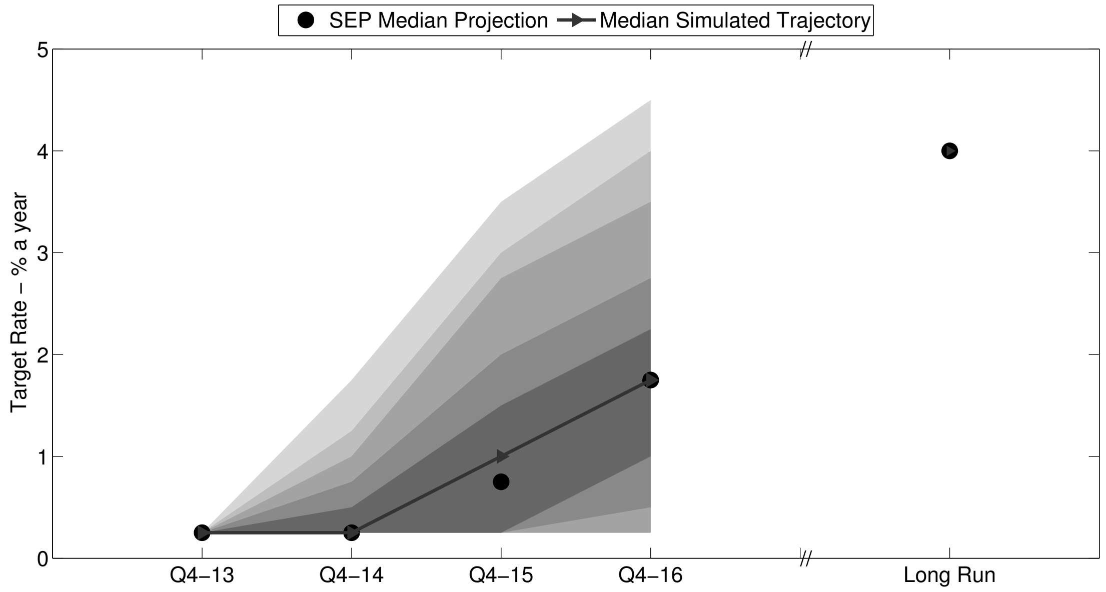

Figure 5.1: Reported, Simulated paths and uncertainty bands using the SW model - December 2013

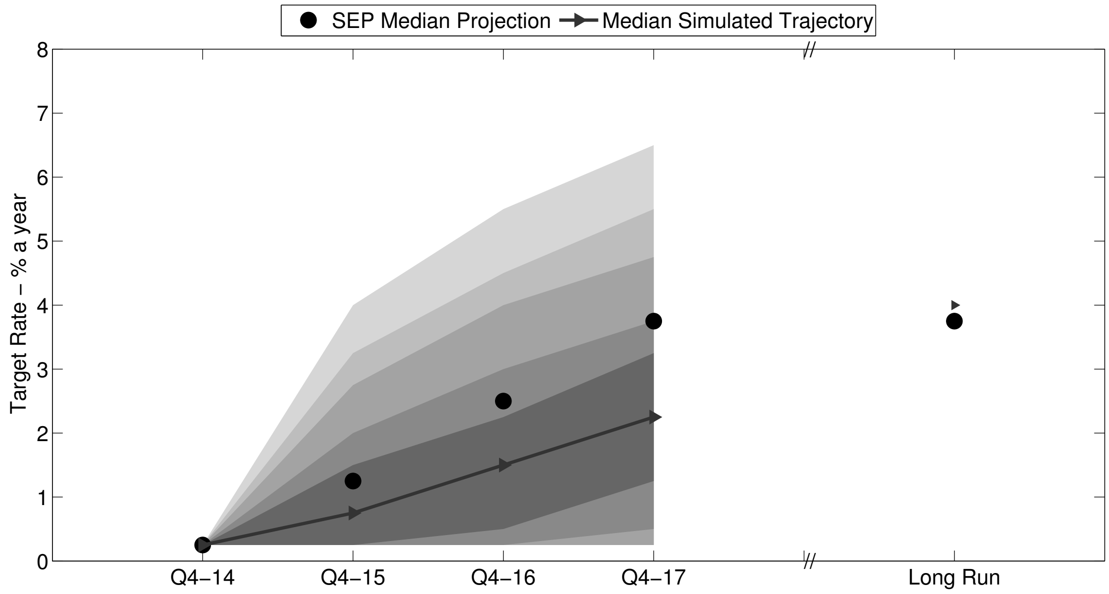

Figure 5.2: Reported, Simulated paths and uncertainty bands using the SW model - December 2014

smoothing coefficient implies a less than perfect commitment behavior by the Federal Reserve, our median simulated trajectory is not as hawkish as the median reported dots. Appendix 8.3 reports the results for all SEP dates.

We also take a more detailed look to establish our lift-off date as of the December 2014 Summary of Economic Projections. Figure 5.3 plots the simulated median path for the nominal interest rate and the uncertainty bands on every year-end from 2012 to 2022, along with the percentiles of the interest rate distribution.

Figure 5.4 plots these data on a quarterly basis for 2014 - 2017. We also compare the simulated trajectory with the end of the year SEP dots and the Fed Funds Future rates. The latter represents the market expectations for the level of the Target Rate as of December 30th, 2014. Results for all SEP dates are available from the authors, upon request.

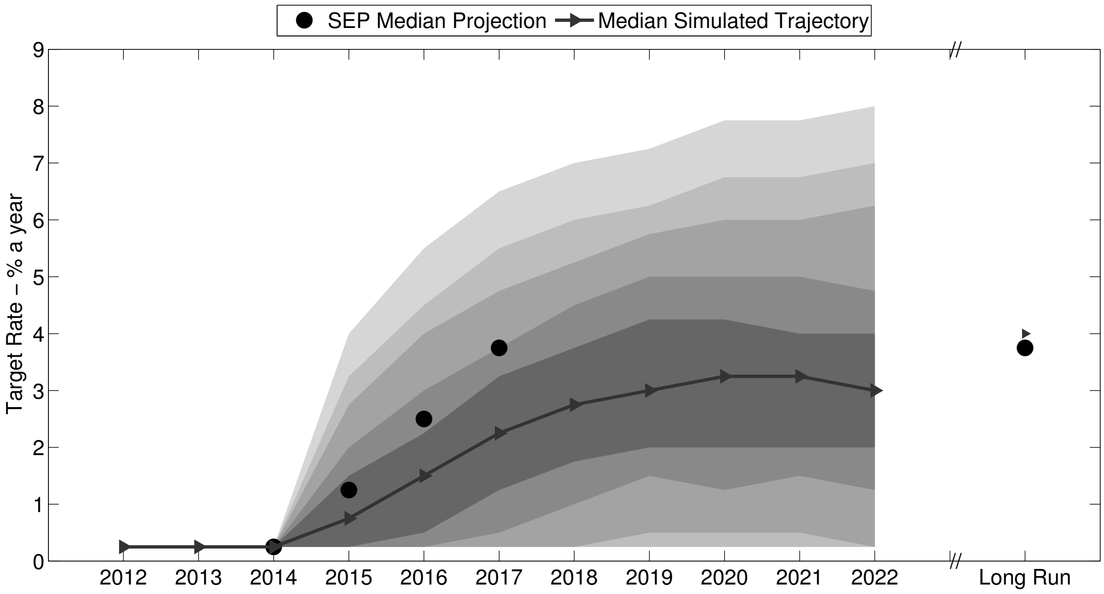

Figure 5.3: Reported and Simulated Paths for the Target Rate - December 2014

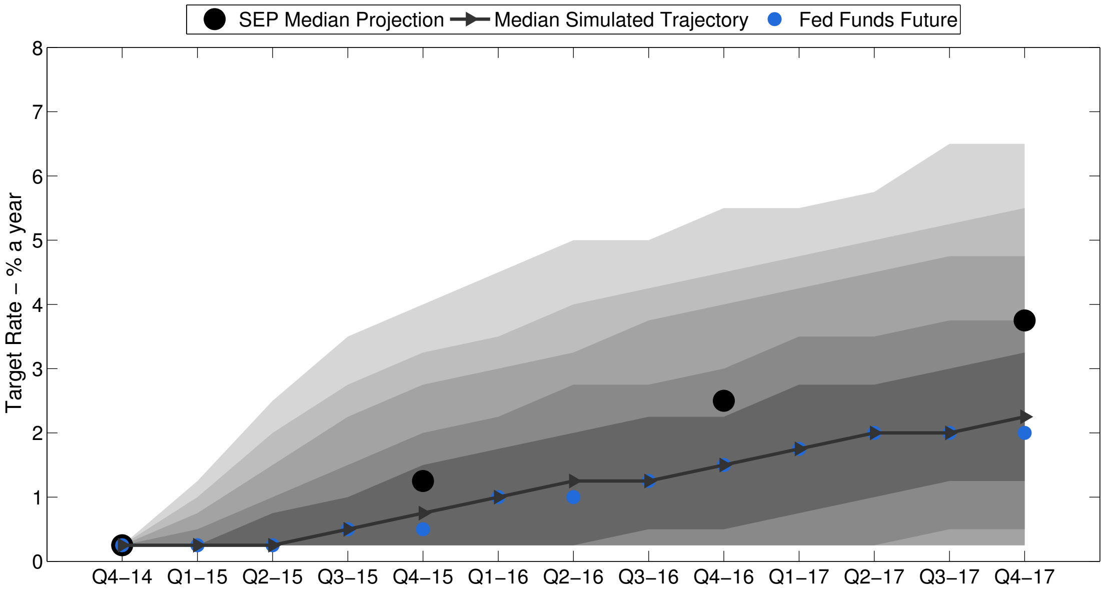

Figure 5.4: Assessing Lift-off: SEP Dots, simulated path and Fed Funds Future - December 2014

Using the SW model, we obtain more realistic results in terms of the uncertainty bands. The introduction of more rigidities in the model implies the percentiles are different from 0.25% or 4% in many quarters.

Our median simulated path for the Fed Funds rate implies a 2015Q3 lift-off. The first increase will be of 25 basis-points, consistent with what the market was expecting in December 2014. Also, the target rate will be at 0.75% by 2015Q4, suggesting that the FOMC will increase rates with considerable caution.

As for the uncertainty regarding the lift-off, the 35th-65th percentiles indicate that the first rate increase might be as early as 2015Q2 but no later than 2016Q3. If we look at more extreme percentiles, the gap is widened. For example, for the 5th-95th percentiles the target rate lift-off should occur sometime between 2015Q1 and 2028Q1. These are big gaps, but one must keep in mind that we are dealing with seven different shocks. In a model with the financial shock alone, the uncertainty is greatly reduced (see Appendix **??**).

It is also worth highlighting that our simulated path closely tracks the Fed Funds Future, which implies a more dovish trajectory than the SEP dots, as has been documented by Bauer and Rudebusch (2013).

Our results change somewhat if we focus on other specifications for the shocks.

If we want to assess the uncertainty regarding the financial shock alone, we can use our specification in which all other shocks are turned-off. In this case, the lift-off projected by the median trajectory is 2015Q4. The uncertainty, as expected, is greatly reduced. The 35th-65th percentiles imply that the lift-off should take place between 2015Q4 and 2016Q2. If we look at the more extreme percentiles, such as the 5th-95th, the uncertainty is also small: 2015Q2 up to 2016Q4.

On the other hand, we might wish to keep all shocks, but draw them from an estimated VAR using the filtered shocks data. This makes sense if one argues that shocks are correlated (which seems to be the case, empirically). Using this specification, the implied lift-off is 2016Q2. The 35th-65th percentiles indicate that the first rate increase should take place sometime between 2015Q3 and 2017Q1.

Finally, our experiment also allows us to gauge how the lift-off uncertainty has changed throughout these years. To do that, we look at the median quarter when the first rate increase is expected to take place for each SEP date. We also assess whether the lift-off band has changed, i.e, the quarter associated with the first increase in the 35th and 65th percentiles. Table 5.2 shows these results. Here we conduct the experiment using only our baseline specification.

Table 5.2: Evolution of the Lift-off Uncertainty[a]

Date of Projection Release	Best-fitting Smoothing Coefficient	Date of lift-off for 65th perc. trajectory	Date of lift-off for median trajectory	Date of lift-off for 35th perc. trajectory
Jan 2012	0.92	2013Q1	2013Q3	2014Q3
Apr 2012	0.92	2013Q3	2014Q2	2015Q1
Jun 2012	0.92	2013Q3	2014Q2	2015Q2
Sep 2012	0.90	2014Q1	2014Q4	2015Q3
Dec 2012	0.94	2013Q3	2013Q3	2014Q1
Mar 2013	0.88	2014Q3	2015Q1	2016Q1
Jun 2013	0.90	2014Q3	2015Q1	2015Q4
Sep 2013	0.80	2014Q3	2014Q4	2015Q3
Dec 2013	0.83	2014Q4	2015Q1	2016Q1
Mar 2014	0.91	2014Q3	2014Q4	2015Q3
Jun 2014	0.63	2014Q4	2015Q1	2015Q2
Sep 2014	0.06	2015Q1	2015Q2	2016Q4
Dec 2014	0.44	2015Q2	2015Q3	2016Q3

[a] Financial shock follows the stochastic two-state process with constant exit probability, and other shocks are NID.

NOTE: Simulations are conducted with 750 draws of shock sequences for each possible value of ρ. Grid considered is between 0.00 and 0.99, with 0.01 increases.

Two results are worth highlighting. First, the lift-off date as implied by the median trajectory has been postponed. For example, for the first five SEPs the initial increase was expected for 2013 or 2014. Second, the lift-off "uncertainty range" (as measured by the number of quarter between the two lift-off date percentiles) has also changed during these years. From an uncertainty of 7 quarters in January 2012 this number was reduced to 3 quarters in June 2014, and then up again to 6 quarters in December 2014.

6
Conclusion

Using data from the Summary of Economic Projections released by the Federal Reserve, we infer the degree of policy commitment at the ZLB. As a by-product, conditional on the inferred policy, we are able to obtain forecasts for the target rate and quantify the uncertainty regarding the lift-off.

We proceed using two different models. The standard New Keynesian model of Eggertsson and Woodford (2003) allows us to solve for the optimal discretion and (full / partial) commitment solutions. However, given the lack of rigidities and the pure forward-looking nature of the model, our estimates are not quantitatively realistic. On the other hand, the Smets and Wouters (2007) model provides results which are more realistic in a quantitative sense. The drawback is that we do not model optimal policy explicitly, rather, we use the interest-rate smoothing coefficient as a proxy: the higher this coefficient, the more we can say monetary policy is time dependent or inertial, bringing the Taylor Rule closer to a commitment behavior.

We find that partial commitment is the behavior which best describes the average reported SEP dots for most dates. This means the Federal Reserve is re-optimizing its state-contingent plan every time it releases new projections. In effect, such behavior is quite discretionary. Similarly, as the SW model shows, the degree of time dependence associated with the Taylor Rule has decreased. This decrease in monetary policy inertia can perhaps be related to the numerous changes made by the committee in its statements. In particular, a move toward a state dependent framework to express forward guidance is followed by a reduction in the best-fitting smoothing parameter. Also, the reduction in the commitment degree increased greatly after the Quantitative Easing tapering began.

Regarding the assessment of the uncertainty in the target rate lift-off, the standard New Keynesian model proves to be of little quantitative use. The percentiles of the simulated fed funds rate distribution imply too large confidence intervals, as measured by the percentiles of the interest rate distribution. The zero lower bound could last as long as 2017Q2 or end as early as the end of 2015. Also, the model predicts the first target rate increase should leave it at 1.25%.

On the other hand, the SW model is much more realistic. Our benchmark specification where the financial shock is a two-state stochastic process and the other shocks are NID implies a lift-off in 2015Q3. As for the uncertainty, the simulated 35th-65th percentiles indicate that the first increase could be as soon as 2015Q2, but no later than 2016Q3.

Our median projection is in line with market's expectations regarding the lift-off, as measured by the Fed Funds Future curve in the end of December 2014. Also, the projected path for the target rate suggests the pace of monetary tightening will be a mild one.

Despite some limitations, the analysis presented here has important consequences. First, we present a method to extract information regarding monetary policy conduct at the Zero Lower Bound using the Summary of Economic Projections. Inferring the degree of commitment is not straightforward in these situations, because the monetary policy instrument does not react to the state of the economy.

Second, we emphasize that the FOMC's degree of policy commitment might change in time. Large-sized models that are constructed with estimation purposes could benefit from the inclusion of this changing nature of the policymaker.

Finally, we bring to attention the fact that the Summary of Economic Projections only reports point estimates of each committee member. There is a considerable uncertainty embedded in these predictions which is not self-evident in the dots. It is important to bear in mind that the lift-off can be substantially anticipated (postponed) if the outlook for the economy turns out to be more (less) favorable.

7
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8
Appendix

8.1
Appendix A: Calibration of the Shock's Exit Probability

In this Appendix we describe the calibration of the shock's exit probability, γ, in more detail. Our purpose is to calibrate the probability so that the central moments (the weighted average or the median) of our simulated fed funds rate distribution matches the SEP dots.

Let N^* denote the number of quarters from a SEP release date until the target rate lift-off. From our assumption on the stochastic process of the shocks, N^* is a random variable. Also, let N^{SEP} denote the number of quarters from a SEP release date until the implied lift-off by that same SEP projections. We calibrate the shock exit probability to satisfy:

$$\gamma | median\,(N^*) = N^{SEP} \tag{8-1}$$

$$\gamma | weighted\ average\,(N^*) = N^{SEP} \tag{8-2}$$

We use equation (8-1) if we want to match the median SEP dots and equation (8-2) if we want to match the average dots, under discretion.

Remember that γ actually refers to the shock's exit probability and not the lift-off probability, and that optimal commitment policy prescribes interest rates should be kept at zero for an extended period, even after the shock has vanished. Hence, equations (8-1) and (8-2) do not take into account this endogenous delay inherent to commitment policies, and therefore, are only correct to calibrate the probability under discretion (when there is no policy delay).

To obtain a correct calibration for the exit probability under commitment, we need to solve the problem of finding a probability that will generate a delay period such that the lift-off of the simulated target rate trajectory is the same as observed in the SEP data. Therefore, we search for a probability γ that will deliver such a trajectory in the neighborhood of the probability computed using (8-1) and (8-2). We do perturbations around the calibrated discretion probability and simulate the model to check if the lift-off date is consistent with SEP data.

There is still a difference between partial and full commitment. Under full commitment, optimization occurs only in 2008Q4. Say we want to calibrate the exit probability for the June 2014 SEP. For a given value of γ, there will be contingencies (shock histories) for which the target rate will be greater than zero for periods earlier than June 2014. We know, however, that is not true. Therefore, we assign zero probability to such contingencies, i.e. we filter them out of our simulation exercise. Under partial commitment such procedure is not necessary because optimization always occurs at the date the SEP is released.

There is yet another aspect of the SEP data which we must take into consideration. The dots only reflect year-end opinions for the target rate. The June 2014 SEP, for example, reports a 1.25% median level for the target rate in the end of 2015. It is unlikely, however, that the first increase happens in 2015Q4. If we were to take that face value, we would bias our calibration of the exit probability, because we would consider a longer lasting endogenous delay.

To solve that, we make a simplifying assumption that once lift-off begins, the FOMC will raise interest rates at a pace of 25bps per meeting until the first end of the year. Therefore, if we observe a 1.25% target rate value in 2015Q4 and we know the FOMC meeting calendar for 2015, we conclude that the lift-off date is in July 2015 (2015Q3). So we actually target 2015Q3 as the lift-off date and not 2015Q4, as the SEP dots would imply.

Our calibration exercise implies there will be a different exit probability under discretion, partial and full commitment. For each SEP and type of behavior, there is not a unique probability that matches the lift-off date rather, a range of probabilities. If we want to target the median SEP dots, the range of calibrated probabilities are given in Table 8.1. Table 8.2 reports the probabilities when we target the average dots. Results shown in the paper do not change if we use any value inside the ranges as our calibration for γ.

The calibration exercise just described is conducted using the standard New Keynesian model, where optimal discretion and commitment policies are available. Such an exercise is not feasible using the Smets and Wouters (2007) model, because we solve and simulate the model for 100 different values of the interest rate smoothing coefficient. Therefore, for the more complex model we simply calibrate the exit probability according to equation (8-1), since we target the median SEP dots. This is equivalent to pick a value for γ inside the range of the third column in Table 8.1.

Table 8.1: Calibrated Exit Probability Under Different Assumptions about Monetary Policy Behavior: Matching the Median SEP Dots

Date of SEP Release	Full Commitment	Partial Commitment	Discretion
January 2012	7.1% - 7.2%	11.1% - 11.2%	5.9% - 6.4%
April 2012	7.4% - 7.5%	13.0% - 13.3%	6.4% - 7.0%
June 2012	6.9% - 7.0%	11.0% - 11.2%	6.4% - 7.0%
September 2012	5.9%	9.5% - 9.6%	5.0% - 5.4%
December 2012	6.6% - 6.9%	9.5% - 9.6%	5.4% - 5.8%
March 2013	7.1% - 7.2%	11.0% - 11.2%	5.9% - 6.4%
June 2013	7.3% - 7.4%	13.0% - 13.3%	6.4% - 7.0%
September 2013	7.5% - 7.7%	15.5% - 15.9%	7.0% - 7.8%
December 2013	8.3%	15.5% - 15.9%	7.8% - 8.8%
March 2014	15.7% - 15.8%	16.0% - 16.5%	8.8% - 10.1%
June 2014	13.0% - 13.1%	20.7%	10.1% - 11.8%
September 2014	16.6% - 16.8%	29.3% - 30.4%	11.9% - 14.2%
December 2014	20.7% - 21.1%	30.5% - 31.9%	14.3% - 17.9%

For the case of Full and Partial Commitment, each cell corresponds to a range of probabilities which yield the same lift-off date as the median SEP dots under the assumption that the FOMC will increase rates 25bps per meeting until the first year-end after the lift-off. For the case of discretion, each cell corresponds to a range of probabilities that satisfy equation (8-1).

Table 8.2: Calibrated Exit Probability Under Different Assumptions about Monetary Policy Behavior: Matching the Average SEP Dots

Date of SEP Release	Full Commitment	Partial Commitment	Discretion
January 2012	1.9%	4.3% - 4.7%	8.7% - 9.5%
April 2012	2.0% - 2.3%	5.4% - 6.6%	10.5% - 11.8%
June 2012	2.0% - 2.3%	5.4% - 6.6%	10.5% - 11.8%
September 2012	2.8% - 2.9%	7.1% - 7.8%	8.7% - 9.5%
December 2012	1.7%	4.2%	8.7% - 9.5%
March 2013	1.8% - 2.0%	4.3% - 4.7%	9.5% - 10.5%
June 2013	2.1% - 2.4%	5.4% - 6.6%	10.5% - 11.8%
September 2013	3.1%	8.3% - 9.2%	10.5% - 11.8%
December 2013	1.6% - 1.7%	4.3% - 4.7%	11.8% - 13.3%
March 2014	1.8% - 2.0%	6.3% - 6.6%	13.3% - 15.4%
June 2014	3.0% - 3.1%	8.2% - 9.3%	15.4% - 18.2%
September 2014	4.0% - 4.1%	10.9%	18.2% - 22.2%
December 2014	7.3% - 7.4%	20.5%	22.2% - 28.6%

For the case of Full and Partial Commitment, each cell corresponds to a range of probabilities which yield the same lift-off date as the average SEP dots under the assumption that the FOMC will increase rates 25bps per meeting until the first year-end after the lift-off. For the case of discretion, each cell corresponds to a range of probabilities that satisfy equation (8-2).

8.2
Appendix B: Additional Figures for Optimal Monetary Policy Behavior under the New Keynesian Model

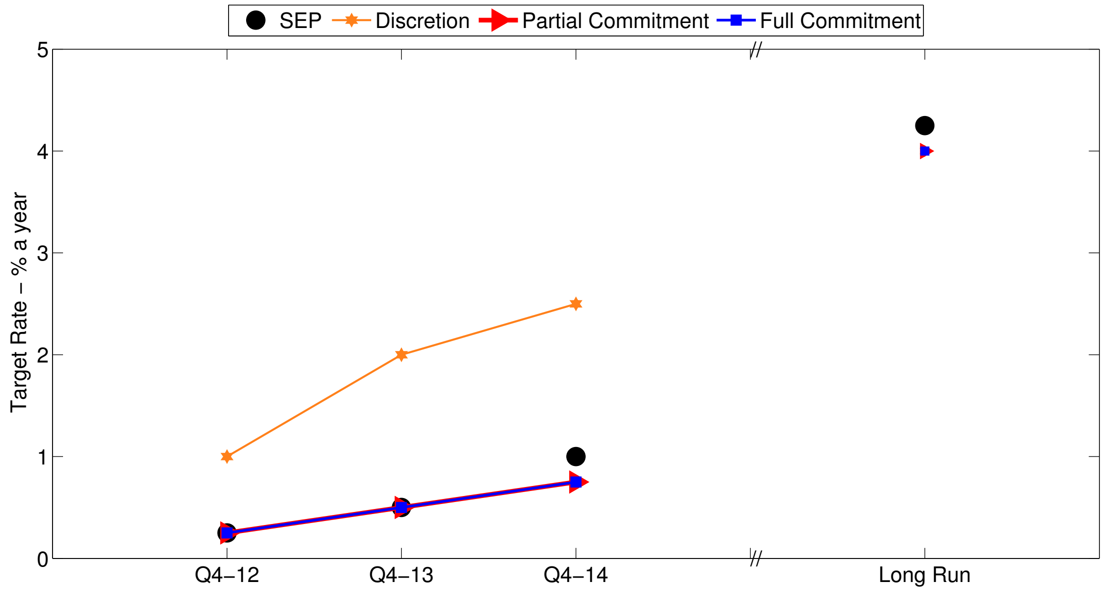

Figure 8.1: Reported and Simulated Paths for the Target Rate using the New Keynesian model - January 2012

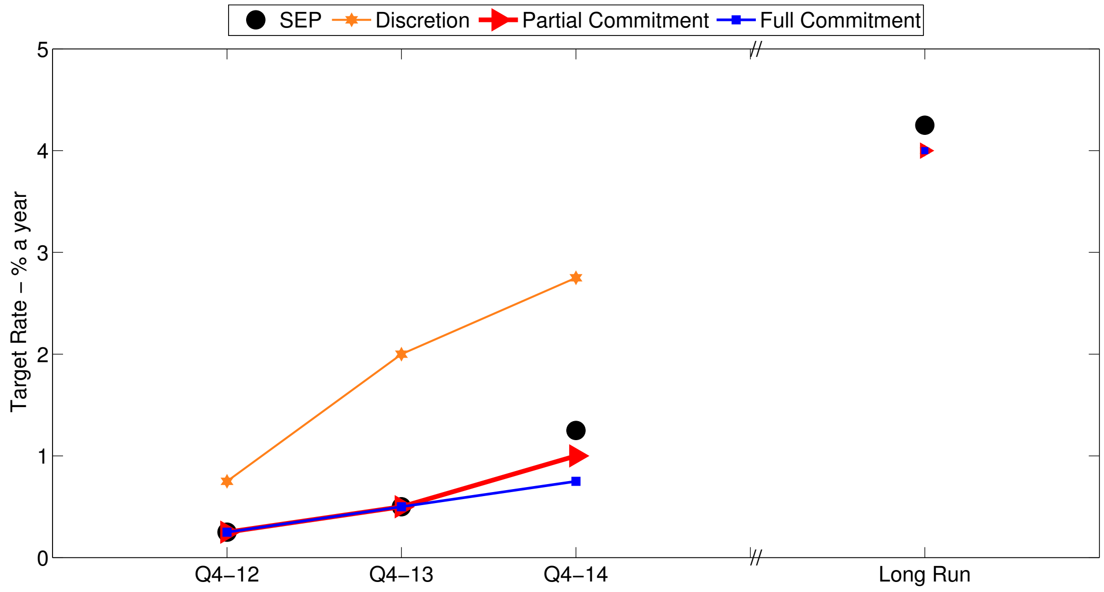

Figure 8.2: Reported and Simulated Paths for the Target Rate using the New Keynesian model - April 2012

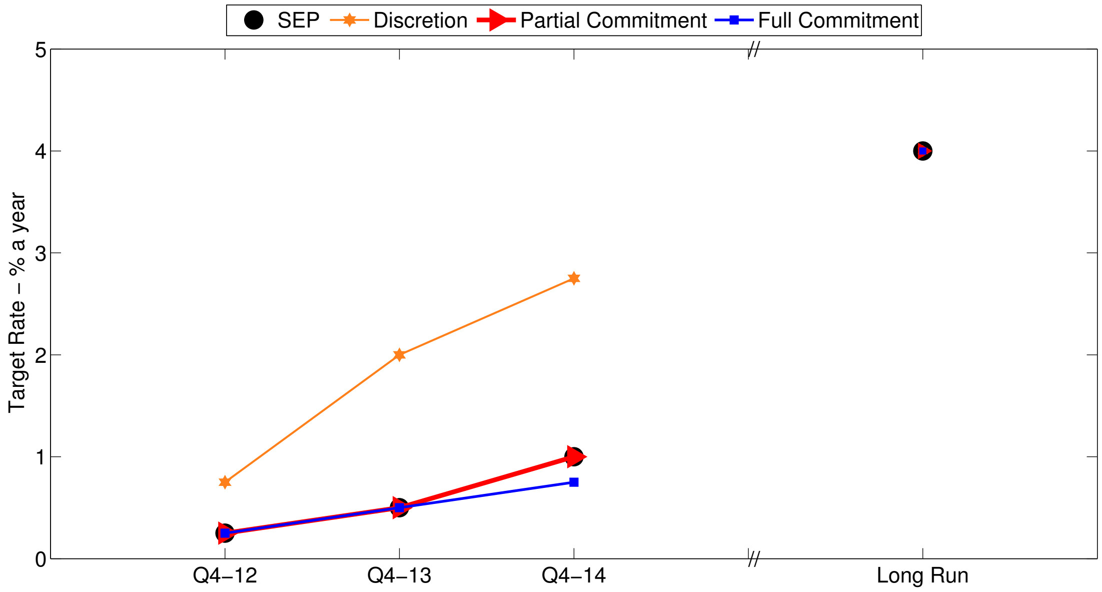

Figure 8.3: Reported and Simulated Paths for the Target Rate using the New Keynesian model - June 2012

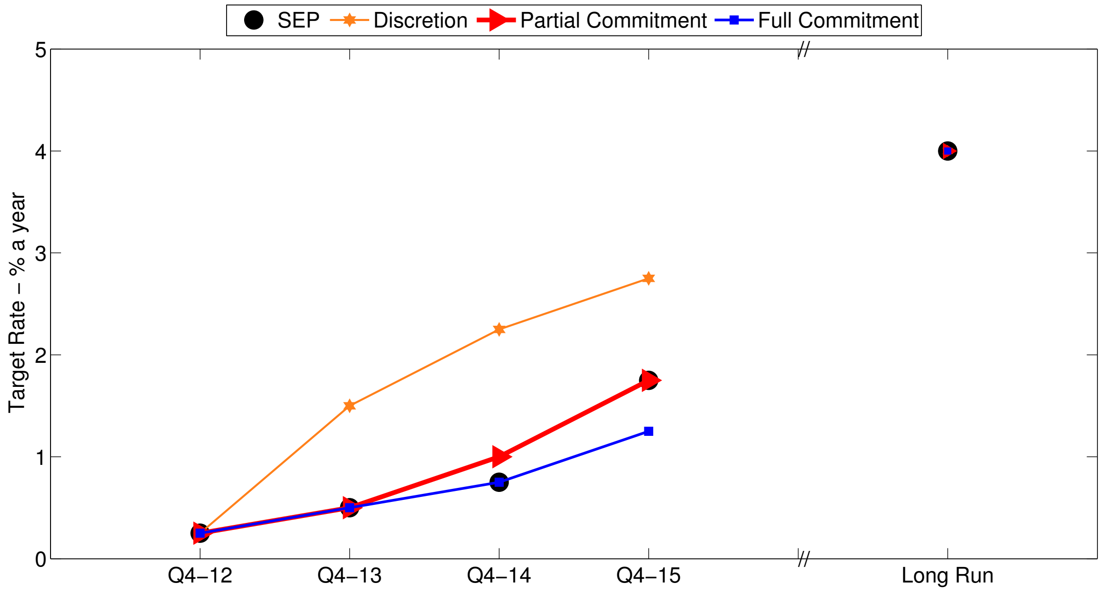

Figure 8.4: Reported and Simulated Paths for the Target Rate using the New Keynesian model - September 2012

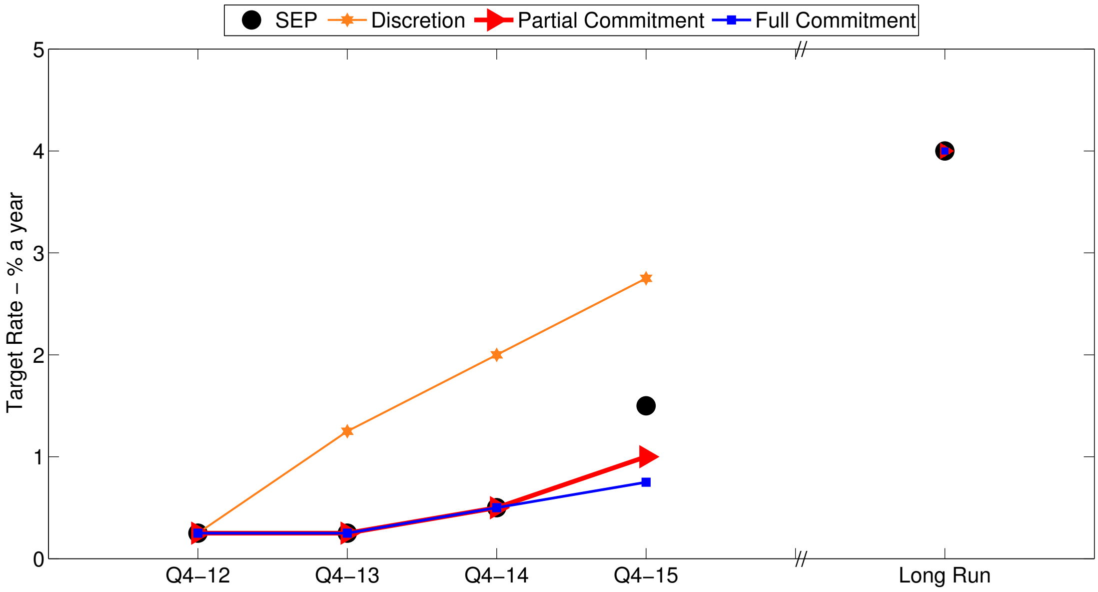

Figure 8.5: Reported and Simulated Paths for the Target Rate using the New Keynesian model - December 2012

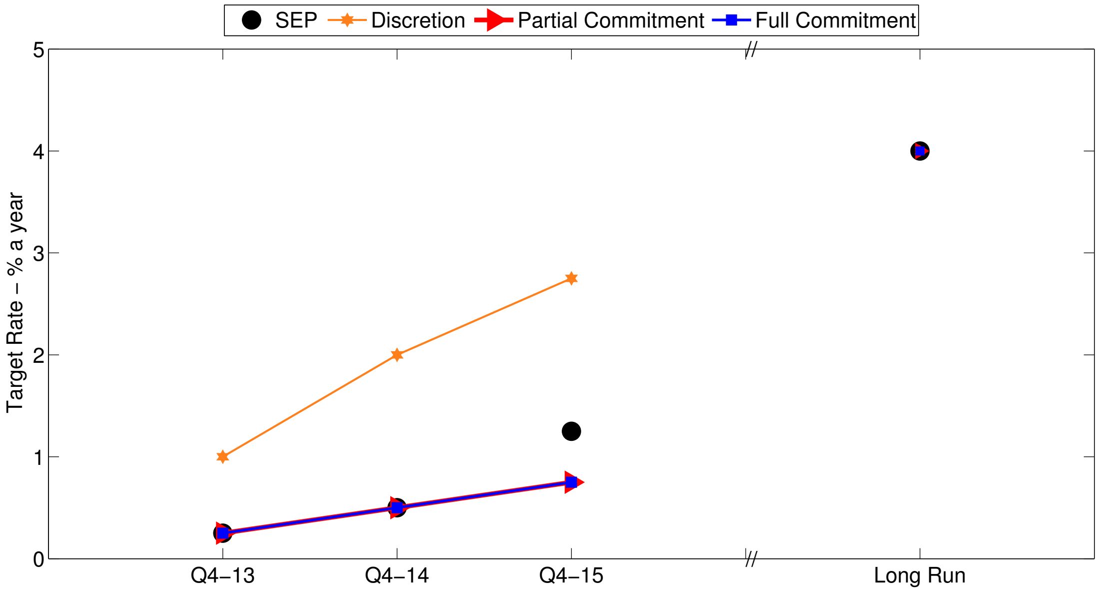

Figure 8.6: Reported and Simulated Paths for the Target Rate using the New Keynesian model - March 2013

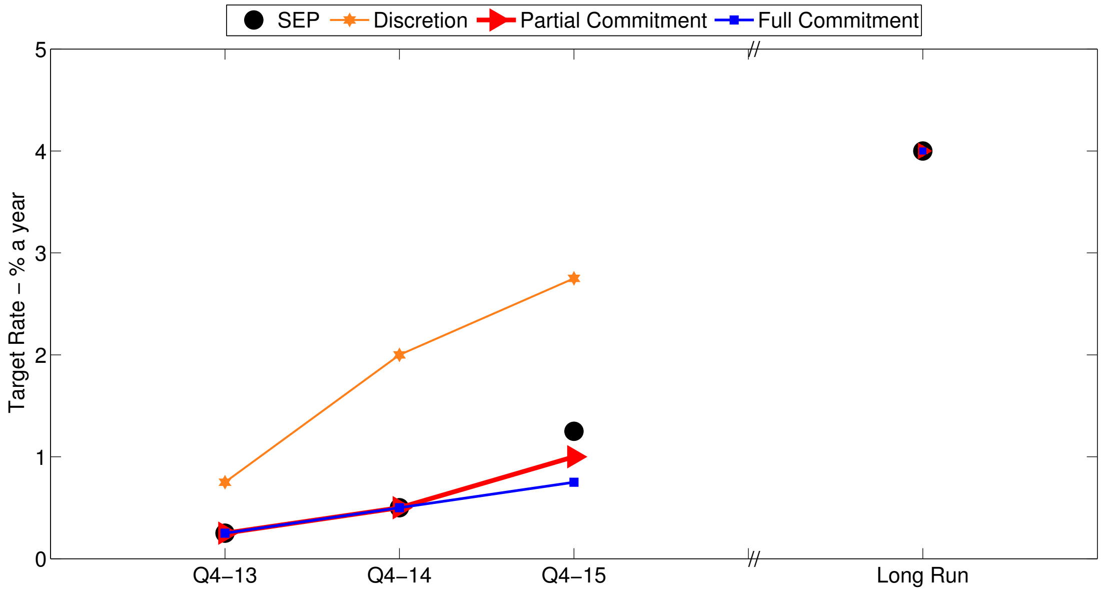

Figure 8.7: Reported and Simulated Paths for the Target Rate using the New Keynesian model - June 2013

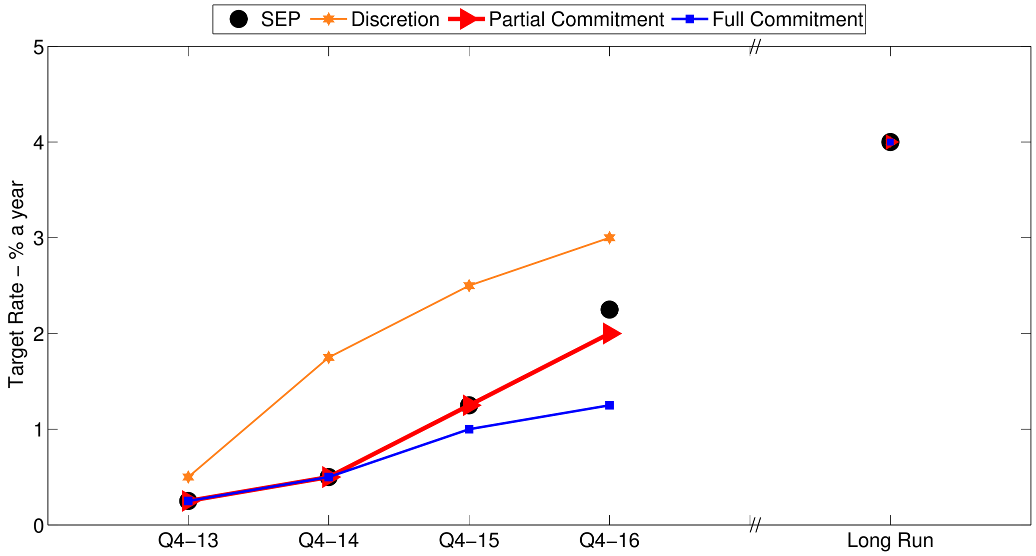

Figure 8.8: Reported and Simulated Paths for the Target Rate using the New Keynesian model - September 2013

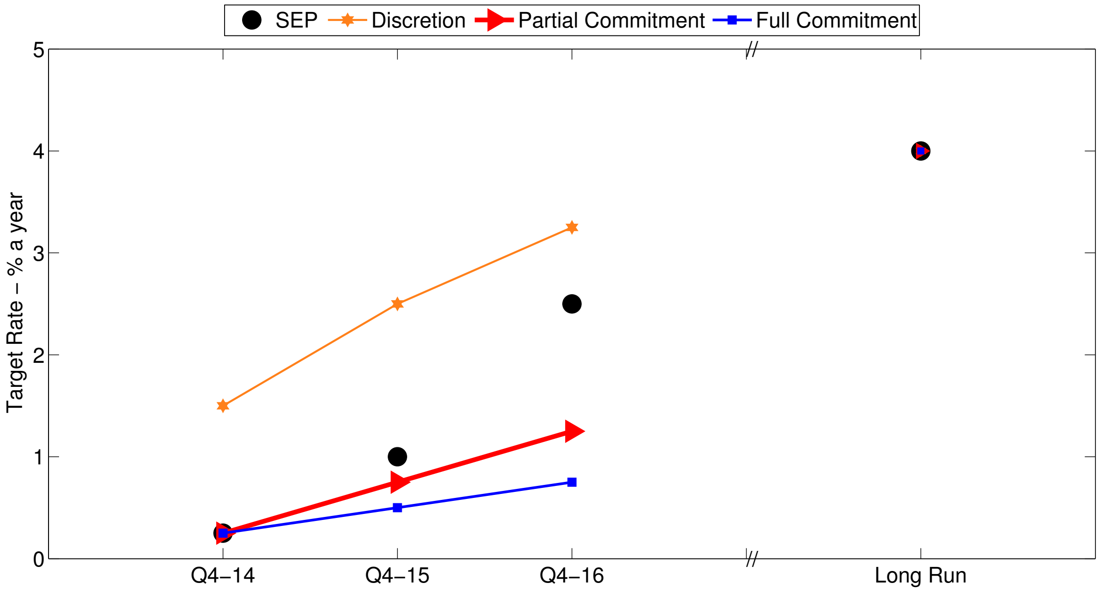

Figure 8.9: Reported and Simulated Paths for the Target Rate using the New Keynesian model - March 2014

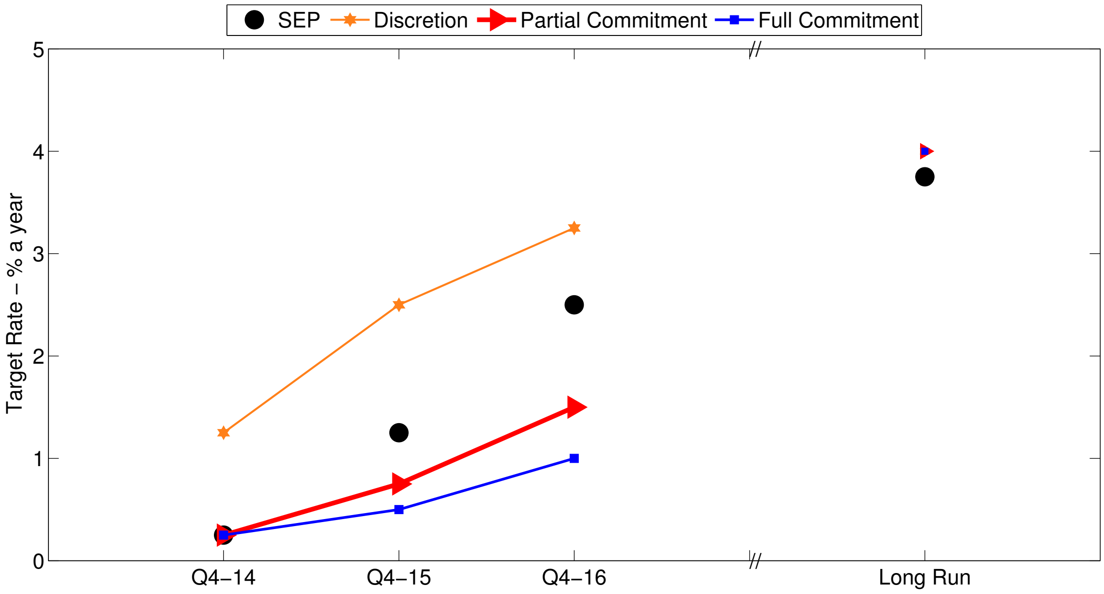

Figure 8.10: Reported and Simulated Paths for the Target Rate using the New Keynesian model - June 2014

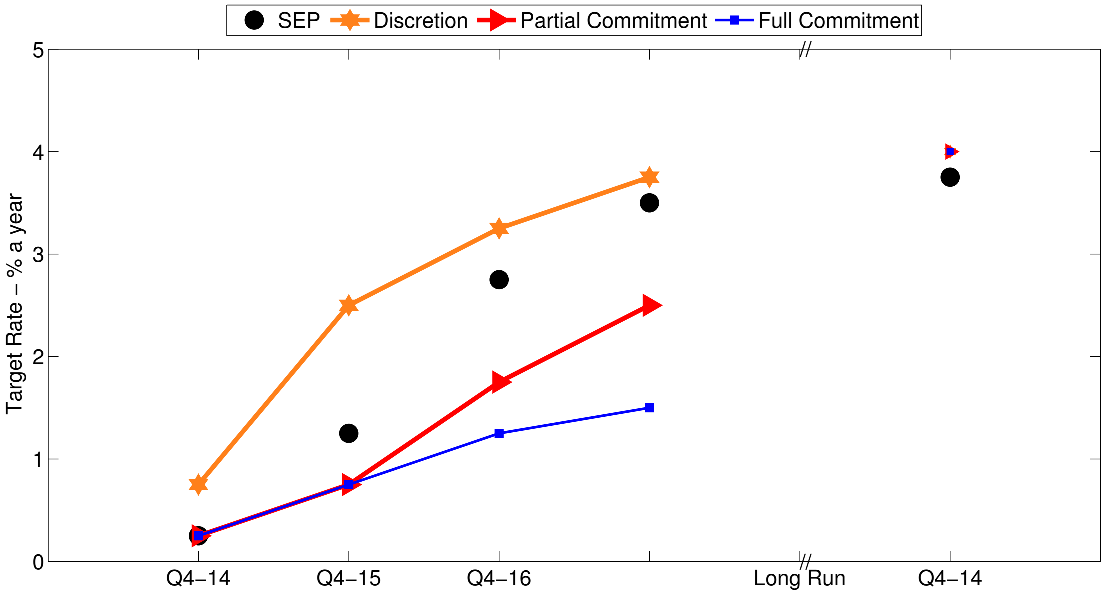

Figure 8.11: Reported and Simulated Paths for the Target Rate using the New Keynesian model - September 2014

8.3
Appendix C: Additional Figures for matching the SEP Dots using the Smets and Wouters (2007) model

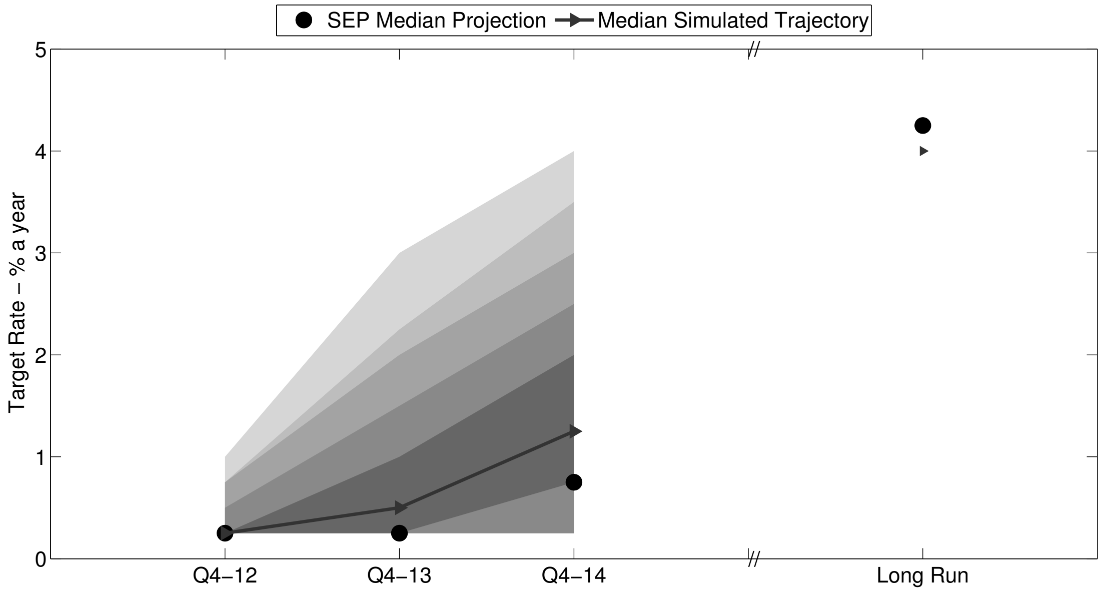

Figure 8.12: Reported, Simulated paths and uncertainty bands using the SW model - January 2012

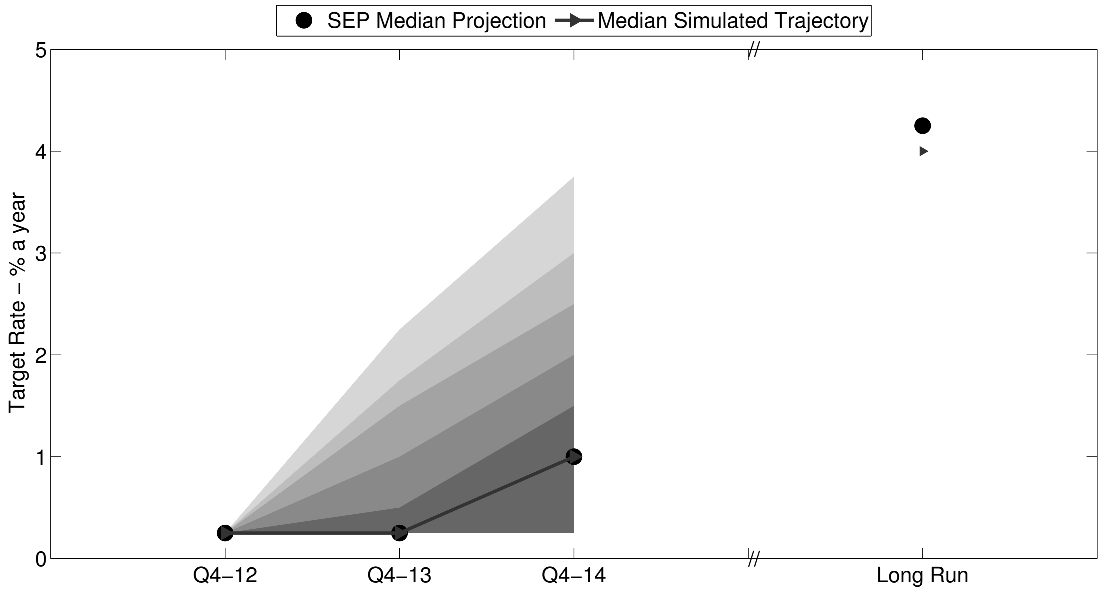

Figure 8.13: Reported, Simulated paths and uncertainty bands using the SW model - April 2012

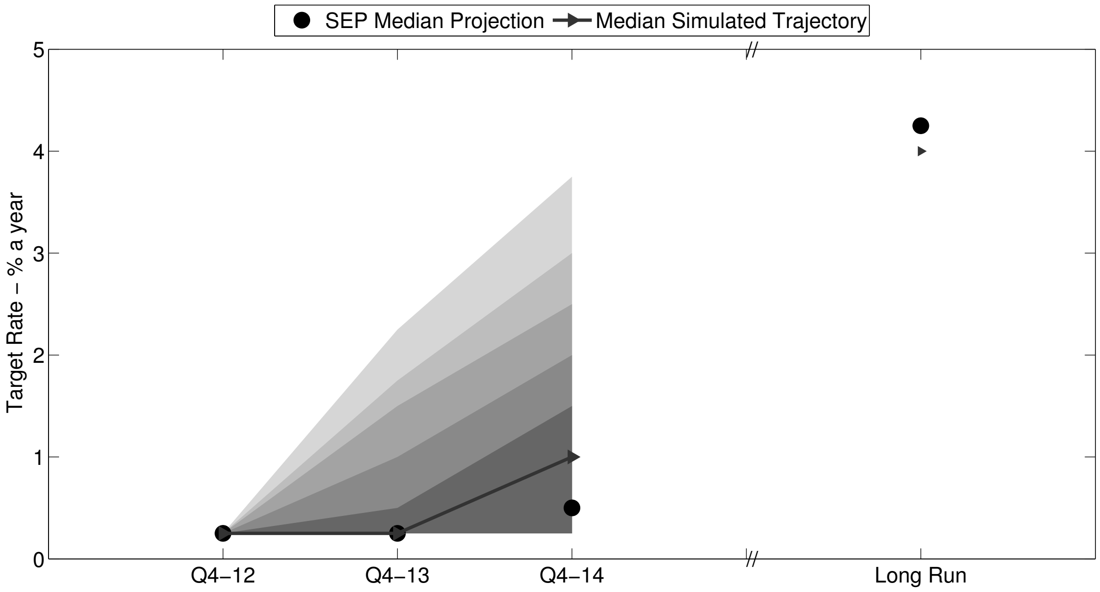

Figure 8.14: Reported, Simulated paths and uncertainty bands using the SW model - June 2012

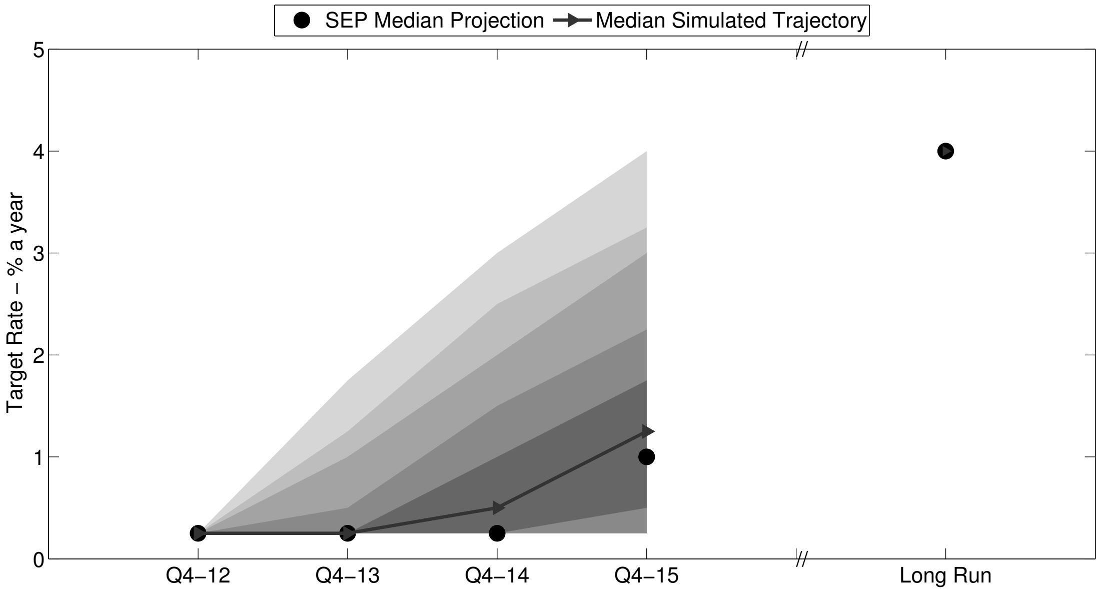

Figure 8.15: Reported, Simulated paths and uncertainty bands using the SW model - September 2012

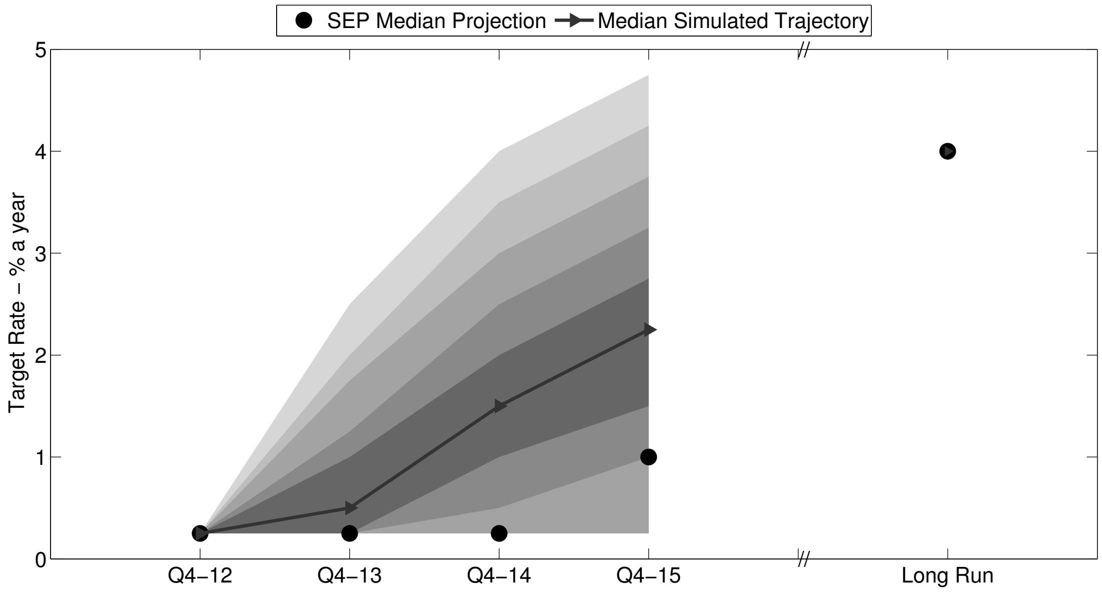

Figure 8.16: Reported, Simulated paths and uncertainty bands using the SW model - December 2012

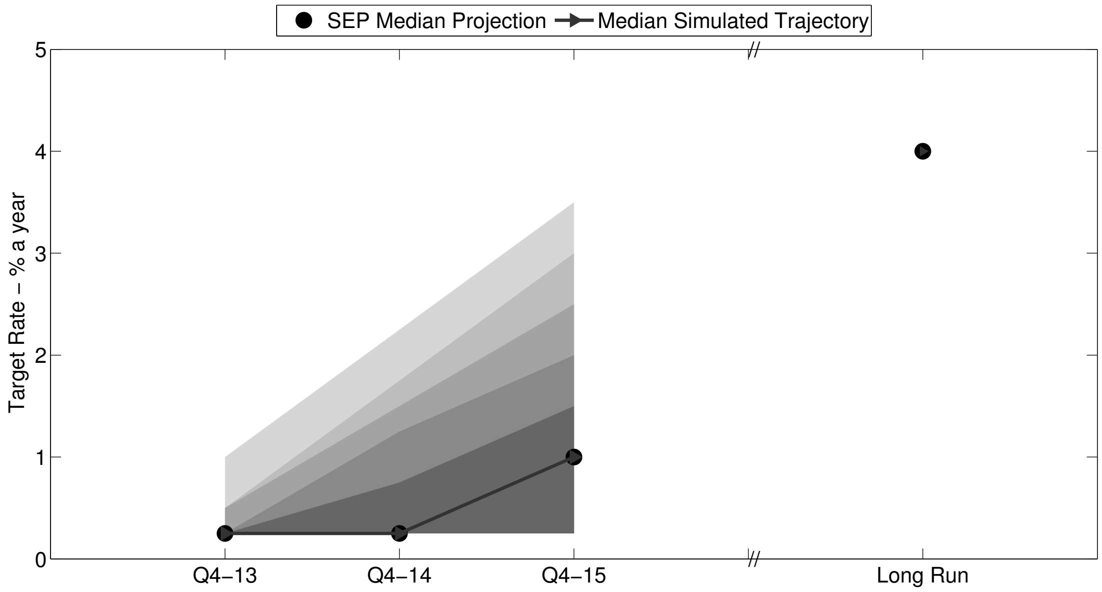

Figure 8.17: Reported, Simulated paths and uncertainty bands using the SW model - March 2013

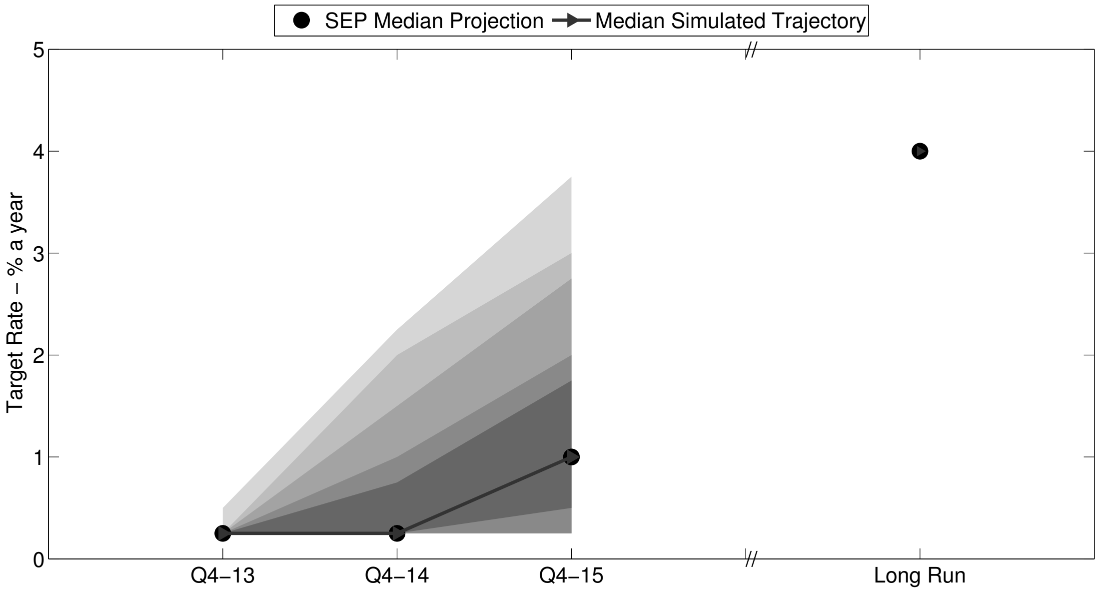

Figure 8.18: Reported, Simulated paths and uncertainty bands using the SW model - June 2013

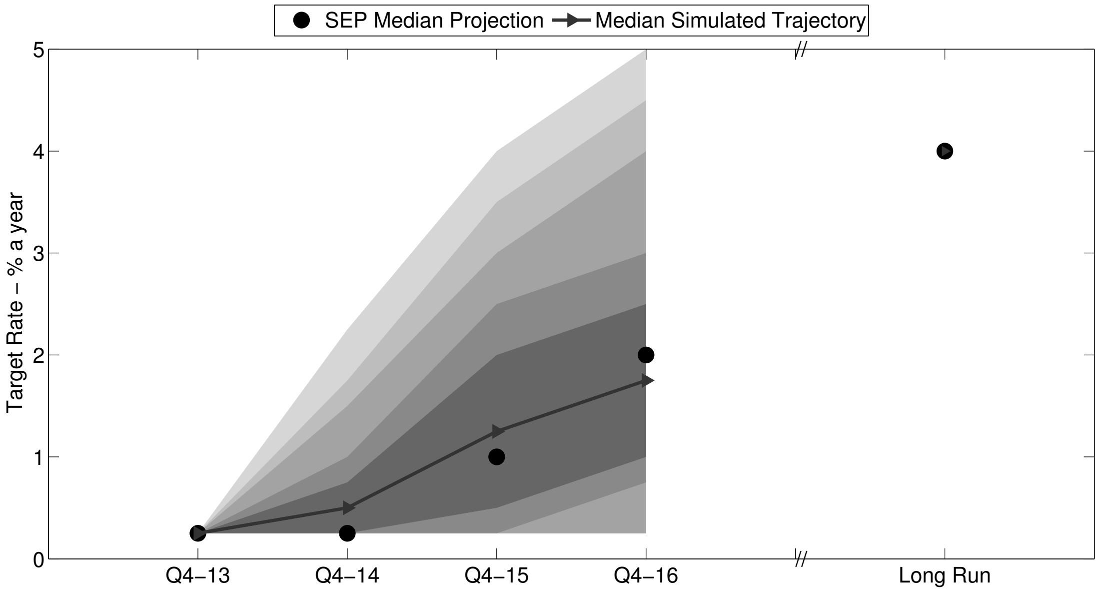

Figure 8.19: Reported, Simulated paths and uncertainty bands using the SW model - September 2013

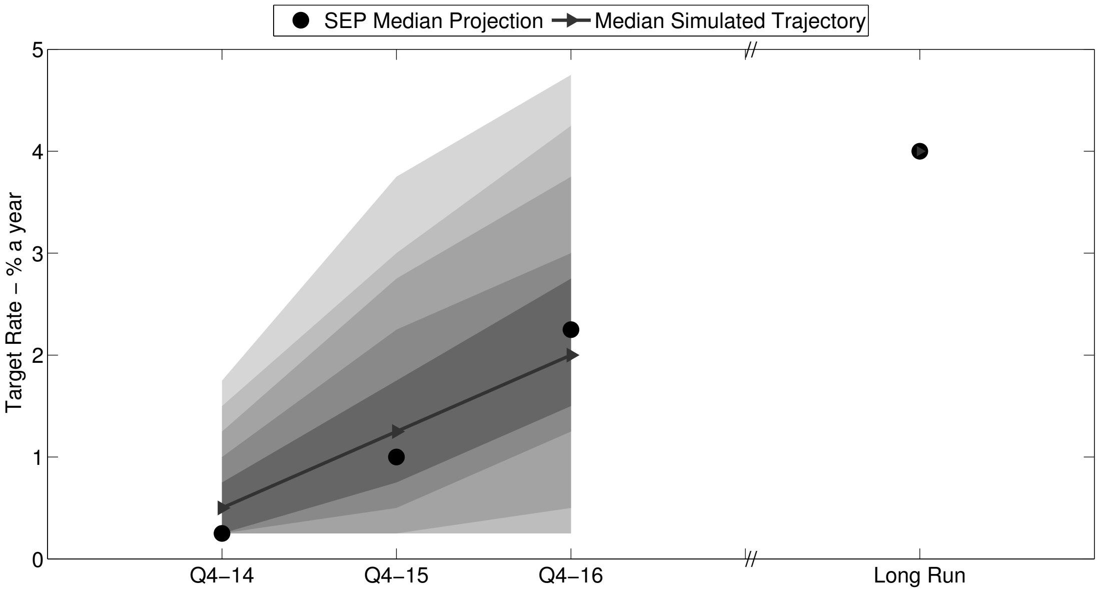

Figure 8.20: Reported, Simulated paths and uncertainty bands using the SW model - March 2014

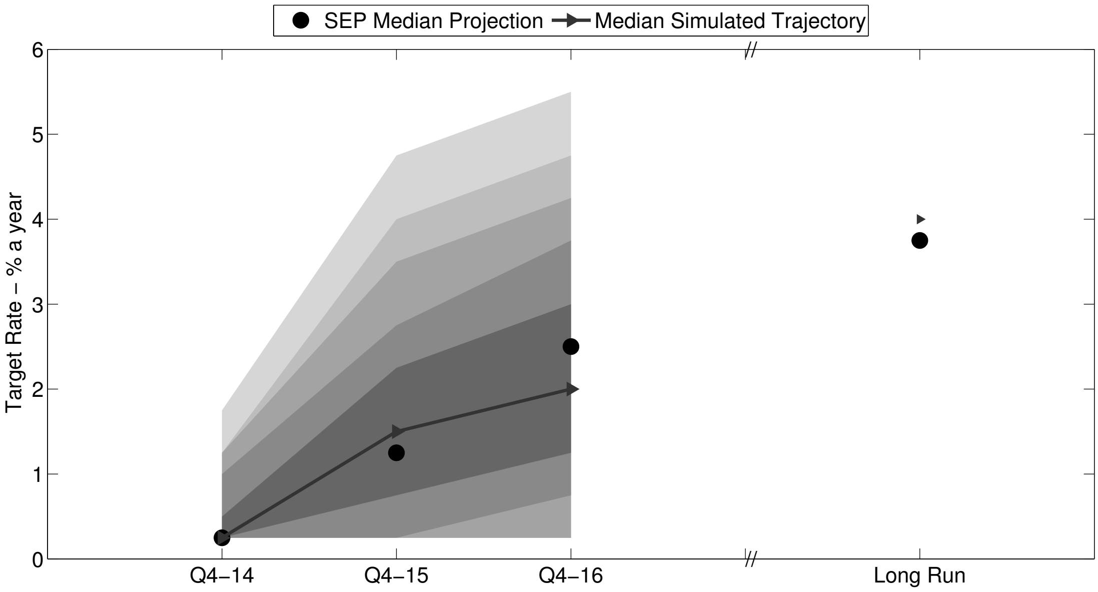

Figure 8.21: Reported, Simulated paths and uncertainty bands using the SW model - June 2014

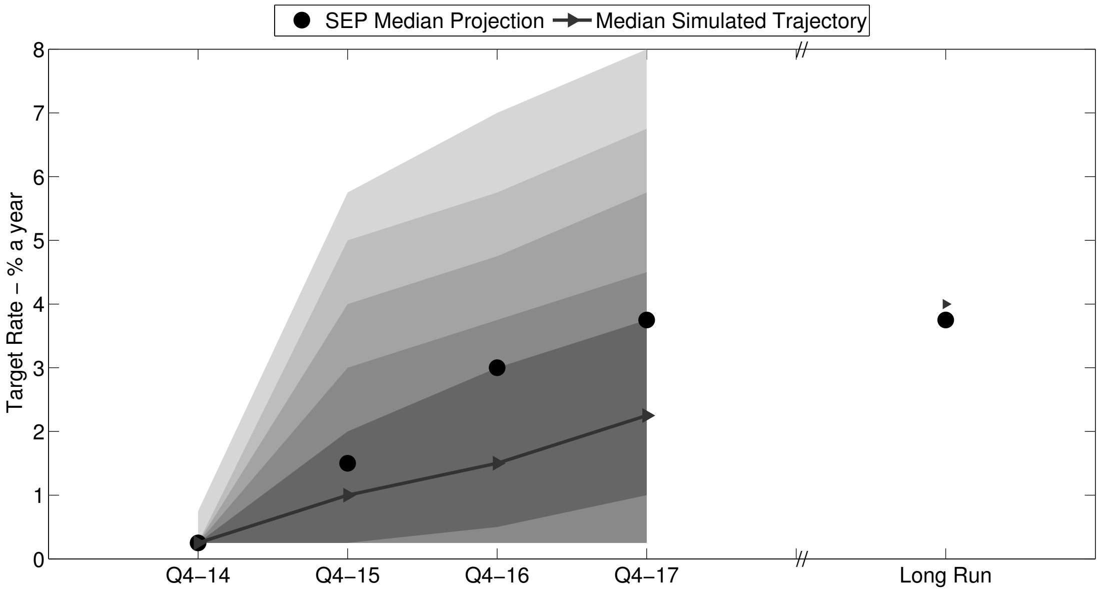

Figure 8.22: Reported, Simulated paths and uncertainty bands using the SW model - September 2014