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Abstract

I decompose deviations of the Federal funds rate from a Taylor type monetary policy rule into exogenous monetary policy shocks and a time-varying inflation target. I show that the role of exogenous shocks may be exaggerated in a fixed inflation target model, and a large fraction of business cycle fluctuations attributed to them may actually be due to changes in the inflation target. A time-varying inflation target explains approximately half of the volatility normally attributed to these deviations, and consequently more than a quarter of the fluctuations in the business cycle. This contributes approximately 39% additional inflation volatility during the Great Inflation. I show that shocks to the inflation target imply a lower sacrifice ratio compared to exogenous changes in the interest rate and therefore propose a gradual adjustment of the inflation target in order to achieve monetary policy objectives.

Keywords: Time-varying monetary policy, inflation volatility, sacrifice ratio
JEL classification: E30, E31, E50, E52, E58

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1. Introduction

In a standard business cycle model, deviations in the Federal funds rate from a Taylor type monetary policy rule are a significant source of business cycle fluctuations (see, for example, Christiano et al. (2005), Gali (2009), Smets and Wouters (2007) and Justiniano and Primiceri (2008)). Primarily documented as the residual of a standard monetary policy feedback rule, the contribution of these shocks may be overestimated if the monetary policy reaction function is misspecified. In such a framework, what is perceived to be an exogenous change in the interest rate could be due to a change in an endogenous but latent variable in the feedback rule. In this context, the model would wrongly attribute a significant fraction of business cycle fluctuations to exogenous changes in monetary policy, which may actually be due to changes in the endogenous part of the feedback rule. By allowing the inflation target to evolve over time, I examine the impact of this type of misspecification in the feedback rule on the magnitude of exogenous monetary policy shocks.

I answer this question in two parts. To disentangle the variation observed in the interest rate from the variation observed in the inflation target, I extrapolate a series for the inflation target from a standard monetary policy reaction function, and use it to estimate a large business cycle model of the U.S. as presented in Smets and Wouters (2007). In the model, the inflation target is included in an otherwise standard reaction function as a stochastic process. I use the results from the estimated model to examine the contribution of the time-varying inflation target on the measurement and the behaviour of exogenous monetary policy shocks by conducting a battery of exercises. The model is also used to study the contribution of the time-varying inflation target on the dynamics of the U.S. economy.

My first set of results suggest that the inflation target rises from 2% in the early 1960s to 7.5% during the 1970s, falling to 1.5% during Volcker's disinflation, and finally stabilizes around 2% during the 1990s. This follows a pattern similar to the model-implied series estimated in Ireland (2005), Milani (2006), and Coibion and Gorodnichenko (2011). Moreover, a time-varying inflation target is found to be an appropriate misspecification to study the evolution of policy shocks compared to other possible misspecifications in the feedback rule. By considering multiple specifications for the inflation target to estimate the model, I rule out the possibility of the Federal reserve responding to structural shocks through adjusting the inflation target, rejecting the conclusions presented in Gavin et al. (2014). Moreover, my baseline findings contribute to the literature examining the role of structural shocks and monetary policy, and rule out the possibility that monetary policy shocks are contaminated with structural shocks.[1] The estimated model with a time-varying inflation target also improves the fit of the Smets and Wouters (2007) model.

My main results show that including a time-varying inflation target leads to a large reduction in the variance of exogenous monetary policy shocks. Comparing exogenous monetary policy generated from a fixed inflation target model with these shocks generated from a time-varying inflation target model suggests that a time varying inflation target can explain up to 47% of the variance attributed to exogenous monetary policy shocks. Estimating a stochastic volatility model with these series confirms this result. Critically, the peak in variance of exogenous monetary policy shocks are highly correlated with the peak in the variance of shocks to the inflation target, strongly suggesting that exogenous changes in the interest rates are correlated with changes in the inflation target. In general, shocks to the time-varying target are highest during the mid 1970s and during the early 1980s, and explain a large fraction of the variation observed in exogenous monetary policy. Therefore, the important policy changes described by Boivin (2005) during this period, and the high volatility of exogenous shocks in post-War U.S identified in Justiniano and Primiceri (2008), may be attributed to changes in the inflation target.[2]

These results contrast sharply with the conclusions based on a model with a fixed inflation target (see, for example, Christiano et al. (2005), Gali (2009) and Smets and Wouters (2007)), and suggest that a fixed inflation target may have overestimated the variance and the contribution of monetary policy shocks to the macroeconomic dynamics. I quantify the role of exogenous shocks in a time-varying target model and compare to the dynamics of these shocks under a fixed inflation target model in the U.S. economy. This framework suggests that traditional exogenous monetary policy shocks have been attributed an excess of 12% volatility in interest rates, 30% volatility in inflation, 24% volatility in output and 27% volatility in labor hours, extending the contribution made by Smets and Wouters (2007) in accounting for the evolution of macroeconomic dynamics in the U.S. In general, these results formalize evidence that the misspecification in the feedback rule may have resulted in overestimating the macroeconomic consequences of pure exogenous changes in the feedback

[1] By allowing structural shocks to be correlated to monetary policy shocks in the model does not improve the fit of the model, nor reduced the estimates of the exogenous policy shocks. Overall these exercises allow me to reject this interpretation of the 'opportunistic approach to disinflation' theory (Orphanides and Wilcox (1996)).

[2] Accordingly, this approach to remove contamination in monetary policy shocks may depict a closer description of monetary policy shocks, and more in line with the classic approach espoused by Friedman and Schwartz (2008), who explain these shocks to be unusual actions of the FOMC given the state of the economy. Romer and Romer (1989)'s approach - which in their own words is quite limited - defines monetary policy shocks as attempts by the Federal reserve to specifically cause recessions, and cure inflation, and therefore excludes both monetary contractions that are generated by concerns other than inflation and all monetary expansions, and is a subset of Friedman and Schwartz (2008)'s original hypothesis.

rule.

Second, I focus on the contribution of the time-varying inflation target on the macroeconomic volatility experienced by the U.S economy during the pre-Volcker period. Since the inflation target is more than twice as volatile in the pre-Volcker period as compared to the post-Volcker period, this increases the volatility of the interest rate rule. My results suggest that approximately 39% of the volatility in inflation may be attributed to the time-varying inflation target,[3] contributing to the findings of Clarida et al. (1998a), Summers (2005), Taylor (1999) and Primiceri (2005). While the quantitative implications of this result are similar to Castelnuovo (2012), my interpretation suggests that frequent changes in the inflation target constitute a policy mistake, which contributed to the macroeconomic volatility experienced by the U.S. during the Great Inflation. Stabilizing the inflation target close to the 2% range during the post-Volcker period might have helped anchor inflation expectations and contributed to macroeconomic stability. Therefore, the time-varying systematic policy rule considered in this paper may partially account for the role of monetary policy in the rise and fall in macroeconomic volatility experienced by the U.S. economy.

Lastly, I study the policy implications of a time-varying inflation target by comparing the effects of an exogenous shock to the inflation target with the effect of an exogenous shock to the interest rate. In the model, the monetary authority can either change the interest rate directly for a given inflation target or change the inflation target. Since the response of output, labor hours and inflation to a shock to the inflation target is very different from a shock to the interest rate, each policy implies economic trade-offs, which are tabulated by calculating sacrifice ratios. In lost output terms, it costs 4.5 times more to cause disinflation when using exogenous interest rate changes compared to changing the inflation target. In my framework the change in the inflation target is implemented gradually giving expectations time to adjust to the new target, causing the output effects of the change in inflation to be much smaller. It is due to this gradual adjustment of the inflation target that my findings contrast with the literature on unannounced changes in the inflation target. For example, Ball and Reyes (2007) find a larger welfare loss associated with changes in the inflation target. My findings are different from existing literature in which sacrifice ratios are studied based only on exogenous changes in the interest rate (see, for example, Cecchetti and Rich (1999)). In general, my results may contribute to reconciling the variability in the range of the sacrifice ratio tabulated across different studies (see, for example, Fuhrer (1994), Wascher et al. (1999), and Cecchetti and Rich (1999)).

[3]Similar to the results found in Smets and Wouters (2007), changes in monetary policy parameters play a negligible role in explaining the Great Moderation

My paper is closely related to Castelnuovo (2012), Ireland (2005), Smets and Wouters (2007) and Fuhrer (1994). Whereas Castelnuovo (2012) focuses on the contribution of shocks to trend inflation on macroeconomic dynamics, my main focus is the impact of misspecifications in the reaction function on exogenous interest rate shocks. Our papers overlap by studying the behaviour of macroeconomic dynamics of time-varying inflation targets. Even on this issue our interpretations differ, since my framework views changes in the inflation targets as deliberate policy actions of the Fed, as compared to his ad-hoc mechanism which stabilizes trend inflation. This has important policy prescriptions as my results suggests that stabilizing the inflation target contributied to macroeconomic stability, a conclusion that is close to the implications forwarded by Tetlow (2008). Moreover, I also focus on the policy implications of these policy shocks. This paper is also different from Ireland (2005), whose primary focus is on the causes and consequences of changes in the inflation target. By extending the contribution to a larger model, I focus on the relationship between changes in the inflation target and the impact on exogenous policy shocks, as well as on macroeconomic dynamics, in light of the extra volatility observed during the Great Moderation. On the policy and sacrifice ratio side, my paper builds on the findings of Fuhrer (1994), who focuses on the sacrifice ratio entailed in the Great Moderation. The main difference between our papers is that I include a time-varying inflation target shock, and interpret it as a deliberate policy action. In this sense, this type of policy enumerates a different sacrifice ratio compared to the sacrifice ratio generated by an exogenous shocks to the interest rate. Finally, this paper rests on the Smets and Wouters (2007) framework but includes a time-varying inflation target, and uses a series for the inflation target obtained outside the model to estimate the full structural model. Therefore, my approach provide the model with extra information in the form of an observable time series for the inflation target.

The paper is presented in the following order: in section 2, I extrapolate an implicit inflation target using a standard monetary policy rule. In section 3, I estimate a large business cycle model of the U.S. with a time-varying inflation target, and discuss the results of the estimation. In section 4, I show that (a) volatility observed as exogenous monetary policy shocks may be partially explained by a time-varying target, (b) study the counterfactual effects on the volatility of the U.S. economy during the subsample periods, and the role of inflation target shocks in the Great Moderation and (c) compare the impact of exogenous movements in the interest rates and compare them with exogenous changes in the inflation targets. Section 5 concludes, with some suggestions for future research.

2. The U.S inflation target

Since the Federal Reserve does not explicitly announce the inflation target, I infer it by applying econometric techniques to historical data. I use this series as an observable to estimate a model of the U.S. economy. To estimate this policy rule, I assume that the behaviour of the monetary authority can be captured by a standard feedback rule, as proposed by Taylor (1993) and generalized in Woodford (2011).[4] I parameterize this policy rule across a wide range of policy parameters to extrapolate multiple possible series for the inflation target.[5]

Since I estimate multiple series for the inflation target that encompass multiple calibrations of the policy parameters, I allow the estimated model to predict the parameters on the feedback rule, and identify the series for the inflation target which best fits the other observed series from actual data. Moreover, I do not impose any restrictive structure on the inflation target, as extrapolating the inflation target with assumptions on the structural model at this stage might contaminate the series. This could lead us wrong attribution of the movement in the inflation target to elements that may not even enter the evolution of the inflation target. I apply maximum likelihood techniques to extrapolate the inflation target from the policy rule using the Kalman filter to estimate the following equation:

$$r_t = \rho_r r_{t-1} + (1-\rho_r)[\phi_\pi[\pi_t - \pi_t^T] + \phi_x x_t] \tag{1}$$

$$\pi_t^T = n_t + \theta_t \tag{2}$$

$$n_t = \rho_\pi n_{t-1} + \epsilon_t^\pi \tag{3}$$

$$\theta_t = \phi_1 \theta_{t-1} + \phi_2 \theta_{t-1} + \epsilon^x \tag{4}$$

In this equation, r_t is the nominal interest rate set by the monetary authority, π_t is annualized inflation and x_t is the output gap. The parameters ϕ_π and ϕ_y represent the degree of policy preferences of the monetary authority to inflation and output, respectively, while ρ_r captures the persistence of interest rates. I assume that the inflation target, π_t^T, is a function of two

[4] A more complicated process for monetary policy, such as the one considered in Coibion and Gorodnichenko (2011), will allow me to identify a similar series for the inflation target but I use this process for its simplicity.

[5] In this context, assuming a widely accepted, monetary policy rule may be fairly standard, the latter assumption regarding the parameters governing the feedback rule may be controversial. Many authors (see, for example, Boivin and Giannoni (2002), Clarida et al. (1998b), Cogley and Sargent (2005), Judd and Rudebusch (1998), and Lubik and Schorfheide (2004)) have argued that US monetary policy was less active against inflationary pressures under the Federal Reserve chairmanship of Arthur Burns than under Paul Volcker and Alan Greenspan. Other studies have found either little evidence of changes in the systematic part of monetary policy (Hanson (2006), Leeper and Zha (2003)) or no evidence of drifts in policy toward a more active behaviour (Sims (1999) and Sims (2001)).

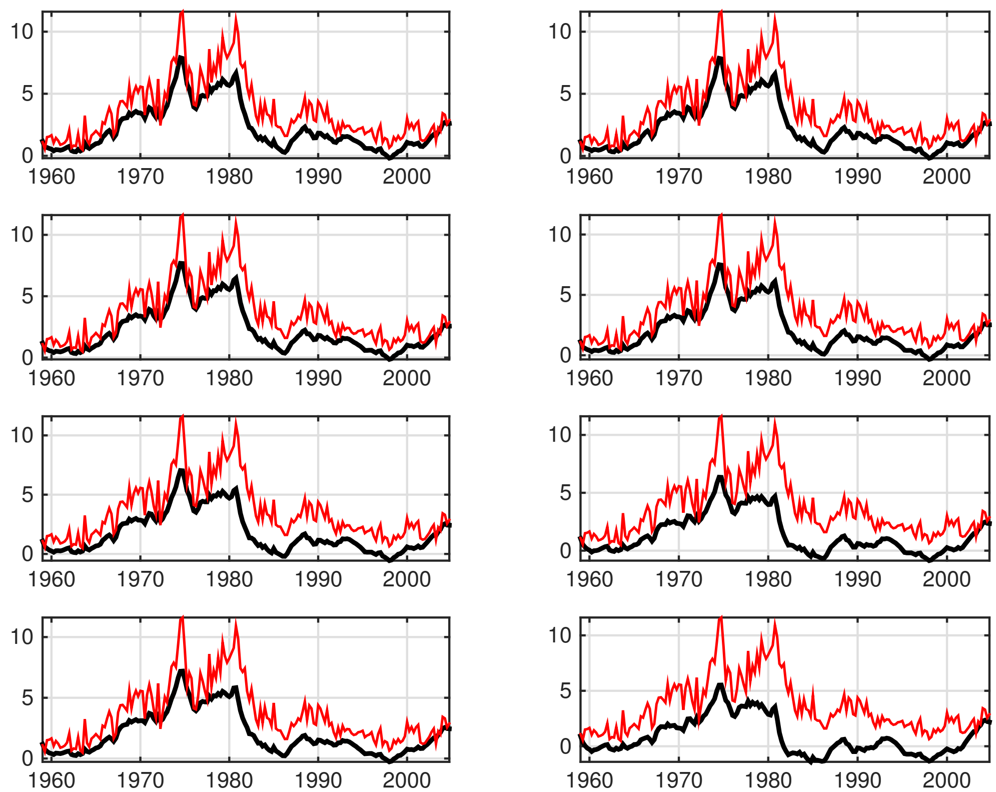
unobservable components, and is represented as the sum of the stationary (n_t) and the non-stationary (x_t) processes. This evolution of the inflation target nests the cases considered in Ireland (2005) and Cogley et al. (2008) as special cases, and is therefore modelled as a stochastic process. Notice that estimating this model will determine the persistence of the model, which in the literature is typically modelled as a very persistent variance-stationary process as presented in Castelnuovo (2012). The series for the inflation target described in equation 1 is extrapolated across different parameterizations of ρ_r, ϕ_π and ϕ_x. Kalman filtering using maximum likelihood techniques is applied to decompose n_t and θ_t and estimate the parameters governing the process, where ρ_π is the persistence of the stationary part of the inflation target, ϵ_t^π may reflect discretionary changes in the inflation target, ϕ_1 and ϕ_2 are the coefficients of the first and second lag, respectively, of the non-stationary part and ϵ^x represents shocks to the white noise process. This specification for the unobservable component allows me to separate the inflation trend from the cyclical component, which may be white noise resulting from data revisions, as suggested in Bernanke and Mihov (1995).

While the natural rate of output and the inflation target cannot be separately identified, I assume that the natural rate is the average of the nominal interest rate over the sample, as also considered by Coibion and Gorodnichenko (2011). Corresponding data is matched as follows: I use quarterly U.S. data on inflation, the output gap, and the federal funds rate, spanning the period between 1959:I and 2004:IV. The output gap is calculated as the log difference between real GDP and the CBO's Potential GDP estimate, inflation is calculated as the quarterly log difference of the GDP Implicit Price Deflator, and the federal funds rate is used in levels and transformed to yield quarterly rates.[6]

Figure 2 plots multiple series for the estimated Federal Reserve's inflation target, as well as annualized inflation during the time period. The time series properties of the evolution of the inflation target are close to the series estimated in Ireland (2005), Milani (2006), and Coibion and Gorodnichenko (2011). The target rises from below 2% in the early 1960s, but quickly moves upward in the late 1960s and early 1970s to values slightly above 4.5%. The inflation target then reaches a peak of around 7% in the early 1970s, before falling to around 1-1.5% during Volcker's disinflation period. The sharp fall in the inflation target during Volcker's disinflation is close to the findings of Tetlow (2000). After 1990, the target stabilizes around 1-1.5% (a large decline in the target is observedat the same time as the 1990-1991 recession, a pattern that is consistent with results obtained in Leigh (2008)). Finally, the target rises back to between 1.75 - 2.5% in 2004.

[6] I also use HP-filtered (Hodrick and Prescott (1997)) output as discussed in Gali (2002) as an estimate of potential GDP to check for robustness, but my main results do not change.

Figure 1: The U.S inflation target



This figure plots the evolution of the U.S. inflation target. The solid red line represents actual inflation from, while the solid black line represents the extrapolated inflation target. The sample covered is from 1959:I through to 2004:IV.

Table 1 tabulates the estimated parameters. My estimates suggest that a high value of the response to inflation, a very low weight on the coefficient on the output gap, and a low weight on interest rate smoothing, as adjudicated by applying the Akaike Information Criterion (AIC), and the Bayesian Information Criterion (BIC) test on the likelihood of the estimation $l(\theta^{ML})$,[7] best represent the data. The persistence of the inflation target is estimated to be high (0.98) while exogenous movements in the inflation target, captured by standard deviation of ϵ_t^{π}, range between 0.68 and 0.75 percentage points. My estimates of the persistence and exogenous components of the inflation target justify the prior used by Ireland (2005) in his model, though my framework explicitly estimates these parameters.

[7] Given a set of candidate models for the data, the preferred model is the one with the minimum value of the AIC/BIC

Given the non-stationary assumption of θ_t, the parameters ϕ_1 and ϕ_2 are both low and have opposite signs, and are not significantly, while shocks to the white noise process are around 0.5 percentage points, and are almost as large as the shock to the inflation target.

Table 1: Inflation target, 1959:1 - 2004:75

Model	Fixed			Estimated Parameters					
	ϕ_π	ϕ_x	ρ_r	ρ_π	ϵ_t^π	ϕ_1	ϕ_2	ϵ^x	$l(\theta^{ML})$
1	4	0.05	0.1	0.98	0.68	0.04	-0.05	0.52	-311.4
2	4	0.05	0.25	0.98	0.69	0.03	-0.05	0.51	-312
3	3.5	0.05	0.25	0.98	0.7	0.05	-0.05	0.5	-312.4
4	4	0.05	0.4	0.98	0.71	0.05	-0.04	0.5	-313.4
5	3	0.05	0.25	0.98	0.72	0.06	-0.05	0.49	-313.5
6	2.5	0.1	0.1	0.97	0.74	0.09	-0.04	0.48	-314.8
7	3.5	0.05	0.5	0.98	0.76	0.07	-0.05	0.47	-317.8
8	2	0.1	0.05	0.96	0.75	0.12	-0.05	0.5	-319.1

The table presents the values of the parameters governing the process for the inflation target using maximum likelihood techniques across different values of the monetary policy rule. The last column presents results of the log-likelihood of the estimation.

3. Model and Estimation

Using the multiple extrapolated series for the inflation target, I estimate a large business cycle model of the U.S. presented by Smets and Wouters (2007), with a stochastic inflation target in the monetary policy feedback rule. In the first step I estimate three versions of the model, using the estimated series for the inflation target. I estimate a model with a fixed inflation target, which forms my benchmark results, a time-varying inflation target model, and an inflation target driven by the structural shocks. From the multiple series for the inflation target, this exercise allows me to infer the best-fit series for the inflation target across the three models. Second, I explore the implications of a time-varying inflation target on exogenous monetary policy shocks, and its contribution to the U.S. macroeconomic dynamics, based on the results of the estimated model.[8]

[8] Once I find the best fitting series given these policy preferences, the model is estimated for different specifications of the feedback rule, across multiple specifications of the inflation target, and structural shocks, which allows me to explore the best-fit specification of the feedback rule. These results are included in the appendix.

3.1. The model

I begin by summarizing the structural mechanism. As is standard in the literature, all variables are log-linearized around their steady-state balanced growth path driven by deterministic labour-augmenting technological progress.

Households Similar to standard smaller models,[9] the economy is populated with a continuum of households with identical preferences that depend on hours worked and consumption. The behaviour of households can be summarised by the dynamic Euler equation: consumption depends on past consumption because of habit formation, on expected future consumption because consumers prefer to smooth consumption, on expected growth in hours worked because of non-separable preferences and on the ex-ante real interest rate of bonds that reflects the intertemporal substitution of consumption. Households also decide how many units of capital services to rent to firms. The Euler equation is summarised by an intertemporal relationship as follows:

$$c_t = c_1 c_{t-1} + (1 - c_1)E_t c_{t+1} + c_2(l_t - E_t l_{t+1}) - c_3(r_t - E_t\pi_{t+1} + \epsilon_t^b) \tag{5}$$

where the the parameters c_1, c_2 and c_3 are functions of the growth rates in the steady state: $c_1 = \frac{\lambda/\gamma}{1+\lambda/\gamma}$, $c_2 = \frac{(\sigma_c-1)(W_*^h L_*/C_*)}{\sigma_c(1+\lambda/\gamma)}$ and $c_3 = \frac{1-\lambda/\gamma}{\sigma_c(1+\lambda/\gamma)}$. The term $\epsilon_t^b = \rho_b\epsilon_{t-1}^b + \eta_t^b$ is a time-varying disturbance representing the wedge between the nominal interest rate controlled by the central bank and the return on assets held by households. In the model, a positive shock increases the return on assets, making households forgo some consumption, which falls. The supply effect causes the cost of capital to rise, and therefore the value of capital and investment falls.

Firms In this economy, firms utilise a certain share, represented by the parameter α, of capital (k_t^s) and labour(l_t) provided by households, to produce output (y_t). Output is affected by total factor productivity (ϵ_t^a) which follow an autoregressive process of order one, $\epsilon_t^a = \epsilon_{t-1}^a + \eta_t^a$. Firms also face some fixed costs in production, controlled by the parameter ϕ_p, which is one plus the share of fixed costs in production. The aggregate production function is given by

$$y_t = \phi_p(\alpha k_t^s + (1 - \alpha)l_t + \epsilon_t^a) \tag{6}$$

Firm specific capital utilization is assumed to evolve such that current capital used in production (k_t^s) is a function of capital installed in the previous period (k_{t-1}) as well as the

[9] See, for example, Gali (2009).

degree of capital utilisation (z_t).

$$k_t^s = k_{t-1} + z_t \tag{7}$$

The accumulation of installed capital (k_t) comes from the dynamic flow of investment, with a share k_1 coming from last period's installed capital, and the rest from this period's investment plus the relative efficiency of these investment expenditures as captured by the investment-specific technology disturbance (ϵ_t^i).

$$k_t = k_1 k_{t-1} + (1 - k_1) i_t + k_2 \epsilon_t^i \tag{8}$$

Since cost minimising households supply capital, the degree of capital utilisation (z_1) will be a positive function of the rental rate of capital (r_t^k). As the rental rate of capital rises, households will forego consumption so they can reap higher profit in the next period.

$$z_t = z_1 r_t^k \tag{9}$$

The degree of capital utilisation is a positive function of the elasticity of capital utilisation ($z_1 = \frac{1-\psi}{\psi}$), where ψ is normalised to be between 0 and 1. A high value of ψ will imply a high cost of changing the utilisation of capital, and when ψ is very low, the marginal cost of changing the utilisation of capital is constant, therefore the rental rate on capital will be constant. In the extreme case when $\psi = 1$, the utilisation of capital will remain constant. The monopolistically competitive firm in the goods markets minimises costs such that the price mark up (μ_t^p) is equal to the difference between the operating marginal product of labour (mpl_t) and the real wage(w_t). The marginal product of labour comes from the first order conditions of the firms maximization problem, and is therefore a positive function of the capital labour ratio and the total factor productivity $mpl_t = \alpha(k_t^s - l_t) + \epsilon_t^a$.

$$\mu_t^p = mpl_t - w_t \tag{10}$$

Combining the equations for the k-period forward looking profit for the firm, which include partial indexation to lagged inflation and price stickiness as per Calvo (1983), prices adjust sluggishly to their desired mark-up. The assumption that all prices are indexed to either lagged inflation or the steady state inflation rate ensures that the Phillips curve is vertical in the long run. The speed of adjustment to the desired mark-up depends on the degree of price stickiness, the curvature of the Kimball goods market aggregator and the steady-state mark-up. In equilibrium the steady state mark-up is itself related to the share of fixed costs in production through a zero-profit condition. A higher mark-up slows the speed of adjustment because it increases the strategic complementarity with other price setters. In a world with fully flexible prices and the price-mark-up shock set to zero, the NKPC reduces to the standard Gali formulation that the price mark-up is constant, or equivalently, that there are no fluctuations between the marginal product of labour and the real wage. Combining these elements gives rise to the augmented New-Keynesian Phillips curve:

$$\pi_t = \pi_1 \pi_{t-1} + \pi_2 E_t \pi_{t+1} - \pi_3 \mu_t^p + \epsilon_t^p \tag{11}$$

Since the parameters π_1, π_2 and π_3 are just functions of the degree of indexation, the steady state trend growth of GDP and the time preference parameter, inflation in this period (π_t) depends positively on past(π_{t-1}) and future inflation (π_{t+1}) and negatively on the current price mark-up. Inflation in this period will be higher if there is a positive shock to the price-mark-up disturbance (ϵ_t^p), which follows an ARMA(1,1) process: $\epsilon_t^p = \epsilon_{t-1}^a + \eta_t^a - \mu_p \eta_{t-1}^a$, where μ_p is an IID normal price mark-up shock. The MA term is included to capture the high frequency fluctuations in inflation. The standard New-Keynesian Phillips Curve can be obtained by setting the indexation parameter (ι) to zero. Given the profit maximisation condition, the rental rate of capital is negatively related to the capital-labour ratio and positively to the real wage (both with unitary elasticity):

$$r_t^k = -(k_t - l_t) + w_t \tag{12}$$

Analogous to the goods market, in the monopolistically competitive labour market the difference between the real wage and the marginal rate of substitution between working and consuming ($mrs_t = \sigma_l l_t + \frac{c_t - \lambda/\gamma c_{t-1}}{1-\lambda/\gamma}$) will be the wage mark-up, where σ_l is the elasticity of labour supply with respect to the real wage and λ is the habit parameter in consumption:

$$\mu_t^w = w_t - mrs_t \tag{13}$$

Similar to the price stickiness, the labour market will have nominal wage stickiness, due to which real wages only adjust gradually to the desired wage mark-up:

$$w_t = w_1 \pi_{t-1} + (1 - w_1)(E_t \pi_{t+1} + E_t w_{t+1}) - w_2 \pi_t + w_3 \pi_{t-1} - w_4 \mu_t^w + \epsilon_t^w \tag{14}$$

Real wage w_t is a function of expected and past real wages, expected, current and past inflation, the wage mark-up and a wage-markup disturbance (ϵ_t^w). In a model with perfectly flexible wages, $\xi_w = 0$, the real wage would be a constant mark-up over the marginal rate of substitution between consumption and leisure. In general, the speed of adjustment to the desired wage mark-up depends on the degree of wage stickiness (ξ_w) and the demand elasticity for labour, which itself is a function of the steady-state labour market mark-up ($\phi_w - 1$) and the curvature of the Kimball labour market aggregator (ϵ_t^w). When wage indexation is zero ($\iota_w = 0$), real wages do not depend on lagged inflation ($w_3 = 0$). The wage-markup disturbance (ϵ_t^w) is assumed to follow an ARMA(1,1) process with an IID-Normal error term: $\epsilon_t^w = \epsilon_{t-1}^w + \eta_t^w - \mu_t^w \eta_{t-1}^w$. As in the case of the price mark-up shock, the inclusion of an MA term allows us to pick up some of the high frequency fluctuations in wages.

Monetary authority The model is closed by introducing a central bank that sets interest rates according to the following feedback rule:

$$r_t = \rho_r r_{t-1} + (1 - \rho_r)[\phi_\pi[\pi_t - \pi_t^T] + \phi_x x_t] + \epsilon_{R,t} \tag{15}$$

I consider two cases for the evolution of the time-varying inflation target. First, I constrain the inflation target to follow an AR(1) process, $\pi_t^T = \rho_\pi \pi_{t-1}^T + \epsilon_\pi$. One possible interpretation for the behaviour of the inflation target is to capture discretionary movements in the inflation target. One reason why I name these shocks as discretionary movements is due to the views presented by Cook (1988) and Taylor (1993) who interpret any interest rate movements as deliberate actions taken by the Federal Reserve. Simply put, one could think of changes in the inflation target as a result of the monetary authorities' imperfect control. In this framework, the central bank systematically sets interest rates, and systematically sets the inflation target in each period but is unable to do so perfectly. Alternatively, the exogenous target model might be reinterpreted in line with the hypothesis presented in Sargent (2001) that Federal Reserve officials actively pushed inflation higher during the 1960s and 1970s in a futile effort to exploit a misperceived Phillips curve trade-off. Or one could think of changes in the inflation target as reflecting the uncertainty in the economy (Tetlow (2000)). In general, however, changes in the inflation target reflect deliberate actions of the monetary authority in my framework.

I also generalize the specification considered in Ireland (2005), and include all structural shocks in the economy to explain the movement in the inflation target.[10] However, unlike their model, I impose no prior restriction on the sign of the response coefficients, δ_j, and they are determined through estimation techniques.[11] I assume that the inflation target in

[10] I consider various combinations of this specification. However, the inflation target as an AR(1) outperforms all alternative cases. These results are available in the appendix.

[11] Once can show that a positive δ_j would imply an accommodating central bank, while a negative δ_j would imply an aggressive central bank.

this case is summarized as follows:

$$\pi_t^T = \rho_\pi \pi_{t-1}^T + \delta_a \epsilon_a + \delta_b \epsilon_b + \delta_g \epsilon_g + \delta_i \epsilon_i + \delta_w \epsilon_w + \delta_p \epsilon_p + \epsilon_\pi \tag{16}$$

The term $\epsilon_{r,t}$, may also represent 'discretionary' exogenous interest rate movements, which follow an AR(1) process, $\epsilon_{R,t} = \rho_r \epsilon_{R,t-1} + \eta_{r,t}$. Finally, the aggregate resource constraint is given by:

$$y_t = c_y c_t + i_y i_t + z_y z_t + \epsilon_t^g \tag{17}$$

where c_y, i_y and z_y are steady state consumption, investment and the capital utilization rate, respectively. Output is therefore used for consumption, investment and capital utilisation z_t, whereas ϵ_t^g represents exogenous demand shocks, which are also affected by productivity shocks: $\epsilon_t^g = \rho_g \epsilon_{t-1}^g + \eta_t^g + \rho_{ga} \eta_{t-1}^a$.

To summarize, the model contains 14 endogenous variables: output, consumption, investment, value of the capital stock, installed stock of capital, stock of capital, capital utilization rate, real rental rate on capital, real marginal cost, real wages, hours worked, interest rate and the inflation target. In addition, eight exogenous autoregressive processes are introduced, with each including an iid-normally distributed error, total factor productivity, investment-specific technology, risk premium, demand shocks, price mark-up, wage mark-up, a monetary policy shock and shocks to the time-varying inflation target.

3.2. Baseline results

In this section, I discuss the results of the estimated model, and compare them with the results presented in by Smets and Wouters (2007), which is re-estimated using Bayesian techniques.[12] In the first step, I shortlist the inflation target series with the highest likelihood of matching the data, by estimating two versions of the model using the nine estimated series of the inflation target, and comparing it with the baseline fixed inflation target model.[13] The modified harmonic mean estimator is used to calculate the BIC/AIC factor, and to identify

[12] The model presented in the previous section is estimated using Bayesian estimation techniques using Monte-Carlo Markov-Chain (MCMC) sampling methods. In general MCMC is a class of methods in which we can simulate draws that are slightly dependent and are approximated from a (prior) distribution. These draws are used to calculate quantities of interest for the (posterior) distribution. The Metropolis-Hastings algorithm allows us to get a complete picture of the posterior distribution, and to evaluate the marginal likelihood of the model, which will be used to compare model fit as normally done in the literature. The procedure for the MH algorithm as well as the prior selection is described fully in the appendix.

[13] I only focus on the results of the best fit series in the section, leaving the estimation robustness across different specifications in the appendix. The robustness exercises allow me to identify the (minor) relationship between structural shocks and monetary policy shocks, and to compare my results with other specifications.

the complete model that best fits the data. Having selected the time series for the inflation target that best matches the observables, I then focus on estimating three versions of the model. I estimate a fixed inflation target model, a time-varying inflation target model, and a model with the time-varying target driven by structural shocks. Table 2 summarizes the fit of these three models. My results suggests that a model with an AR(1) time-varying target fits the data better than a model with a time-varying target driven by structural shocks, but a model with a time-varying inflation target strictly fits the data better compared to a constant inflation target model.

Table 2: Model Fit

Model	Parameters	ML	BIC	AIC
Fixed Target	36	-963.61	2100.9	1999.9
AR(1) TV target (TV - I)	39	-810.09	1817.1	1698.2
TV target with shocks (TV - II)	45	-921.27	2069.8	1932.5

The table presents the value of the BIC test for a fixed inflation target model, a model with a time-varying inflation target which follows an AR(1) process, and a time-varying target driven by the structural shocks.

I now focus on the estimated parameters from these three models. First, table 3 focuses on the estimates of the structural parameters. The adjustment cost parameter, habit formation, probability of wage change, price indexation, and the share of labour in production are estimated to be around 6.2, 0.78, 0.65, 0.18 and 0.25, respectively. The fixed target model suggests that firms reset prices every six months, while both time-varying target models suggest that firms reset their prices more often, and the price reset time is almost every 2.5 months. Wage indexation is also estimated to be lower in both time-varying inflation target models. The posterior mean of the fixed cost parameter is estimated to be much higher than assumed in the prior distribution (1.65) across the three models, but the intertemporal elasticity is estimated to be similar to the prior (1.5), and similar across the three models. The elasticity of labour supply under the fixed target model and under a time-varying target model suggests a value around 2, which is quite different from the prior.

Table 3: Prior and Posterior Estimation of the Structural Parameters

Parameters	Prior	Dist.	Fixed	TV - I	TV - II
φ	4.2	Normal	6.1	7.2	6.65
σ_c	1.56	Normal	1.58	1.4	1.6
λ	0.67	Beta	0.78	0.8	0.78
ϵ_w	0.672	Beta	0.66	0.63	0.67
σ_l	1.404	Normal	1.27	1.52	2.27
ϵ_p	0.61	Beta	0.55	0.59	0.60
ι_w	0.5	Beta	0.63	0.52	0.36
ι	0.5	Beta	0.2	0.13	0.18
ψ	0.5	Beta	0.5	0.33	0.27
ϕ_p	1.25	Normal	1.67	1.68	1.55
α	0.36	Normal	0.26	0.36	0.29

The table presents the prior and the posterior estimates of the structural parameters. The columns denote the results from estimating each type of model, 'Fixed' for the fixed inflation target model, 'TV - I' represents a model with a time varying inflation target with structural shocks, while 'TV - II' represents a model with an AR(1) inflation target.

Table 4 focuses on estimates of the monetary policy parameters. The mean of the long run reaction coefficient to inflation is estimated to be relatively high and is around 2.5 under a fixed target model, and 2.8 and 3 in both time-varying inflation target models. There is a considerable degree of interest rate smoothing, as the mean of the coefficient on the lagged interest rate is estimated to be 0.81 under all three models. Policy does not appear to react very strongly to the level of the output gap (0.09). The persistence of monetary policy shocks is estimated to be 0.32 in the fixed target model, 0.22 in the time-varying target model, where the target is driven by structural shocks, and 0.17 in the time-varying target model with the AR(1) specification. Standard errors of monetary policy shocks are estimated to be 0.26 in the fixed target model, and 0.22 in both time-varying target models. The process for the inflation target is highly persistent, at around 0.95, and the standard deviation is 0.07 under both specifications of the inflation target. Since the shock to the inflation target is much more persistent than an exogenous shock to the interest rate, it may explain the persistent changes in the interest rate at longer horizons.

Table 4: Prior and Posterior Estimation of the Policy Parameters

Parameters	Prior	Dist.	Fixed	TV - I	TV - II
ρ_r	0.25	Beta	0.81	0.8	0.81
ρ_π	0.9	Beta	-	0.96	0.95
ρ_m	0.37	Beta	0.32	0.23	0.18
ϕ_π	3	Normal	2.55	2.82	3
ϕ_y	0.05	Normal	0.15	0.09	0.09
σ_m	0.09	IG	0.26	0.25	0.25
σ_π	0.27	IG	-	0.07	0.07
δ_a	0	Normal	-	0.0053	-
δ_g	0	Normal	-	0.0090	-
δ_b	0	Normal	-	-0.0073	-
δ_i	0	Normal	-	0.0019	-
δ_w	0	Normal	-	0.0019	-
δ_p^p	0	Normal	-	-0.0077	-

The table presents the results of the prior and the posterior estimates of the monetary policy parameters. The columns denote the results from estimating each type of model, 'Fixed' for the fixed inflation target model, 'TV - I' represents a model with a time varying inflation target with structural shocks, while 'TV - II' represents a model with an AR(1) inflation target.

Estimates of the main macroeconomic variables are summarised in table 5. The posterior mean of the steady-state inflation rate over the full sample is around 3 percent on an annual basis, as estimated in Smets and Wouters (2007). The mean of the discount rate is estimated to be quite small (0.65 percent on an annual basis). For the time-varying target model, the steady-state inflation rate over the full sample is around 2.5 percent on an annual basis. The trend growth rate is estimated to be around 0.60, which is approximately the average growth rate of output per capita over the sample. The implied mean steady-state nominal and real interest rates are, respectively, about 6 percent and 3 percent on an annual basis.

Table 5: Prior and Posterior Estimation of steady state variables

Parameters	Prior	Dist.	Fixed	TV - I	TV - II
$\bar{\pi}$	0.67	Gamma	0.67	0.67	0.55
$\bar{l}$	0.69	Normal	0.13	0.81	1.58
$\bar{\gamma}$	0.5	Gamma	0.60	0.67	0.67
$100(\beta^{-1}-1)$	0.21	Gamma	0.25	0.12	0.19
$\bar{\pi}^T$	0.53	Gamma	-	0.47	0.53

The table presents the results of the prior and the posterior estimates of the underlying steady state variables. The columns denote the results from estimating each type of model, ‘Fixed’ for the fixed inflation target model, ‘TV - I’ represents a model with a time varying inflation target with structural shocks, while ‘TV - II’ represents a model with an AR(1) inflation target.

Productivity, demand, inflation mark-up and wage mark-up shocks are estimated to be the most persistent, with persistence greater than 0.90 across the three models estimated. The high persistence and the standard deviation of productivity and demand (greater than 0.40 across the three models) implies that at long horizons, most of the forecast error variance of the real variables will be explained by those two shocks. Investment specific technology and finance premium shocks are estimated to be less persistent, with persistence and standard deviation around 0.60, and 0.25 respectively. Investment specific technology has standard errors of around 0.50, while finance premium shocks have standard errors of around 0.30 across the three models.

Table 6: Prior and Posterior Estimation of Shock Processes

Parameters	Prior	Dist.	Fixed	TV - I	TV - II
ρ_a	0.97	Beta	0.98	0.96	0.97
ρ_b	0.21	Beta	0.13	0.34	0.25
ρ_g	0.85	Beta	0.97	0.96	0.96
ρ_q	0.36	Beta	0.7	0.64	0.64
ρ_m	0.37	Beta	0.32	0.22	0.17
ρ_p	0.87	Beta	0.99	0.98	0.99
ρ_w	0.74	Beta	0.97	0.85	0.96
σ_a	0.53	IG	0.46	0.45	0.48
σ_b	0.29	IG	0.27	0.23	0.25
σ_g	0.52	IG	0.53	0.52	0.52
σ_q	0.65	IG	0.48	0.48	0.50
σ_m	0.09	IG	0.26	0.23	0.22
σ_p	0.09	IG	0.13	0.15	0.15
σ_w	0.26	IG	0.27	0.27	0.26

The table presents the results of the prior and the posterior estimates of the shock processes. The columns denote the results from estimating each type of model, 'Fixed' for the fixed inflation target model, 'TV - I' represents a model with a time varying inflation target with structural shocks, while 'TV - II' represents a model with an AR(1) inflation target.

4. The dynamics of the U.S economy

Using the results of the estimated model, I examine the quantitative implications of a time-varying inflation target on exogenous monetary policy shocks. I study the role of the time-varying inflation target in generating additional volatility during the pre-Great Moderation era. Finally, I present policy implications of exogenous shocks to the interest rate by computing the sacrifice ratios of the U.S. economy, comparing exogenous shocks to the inflation target with exogenous changes in the interest rate.

4.1. A tale of two shocks

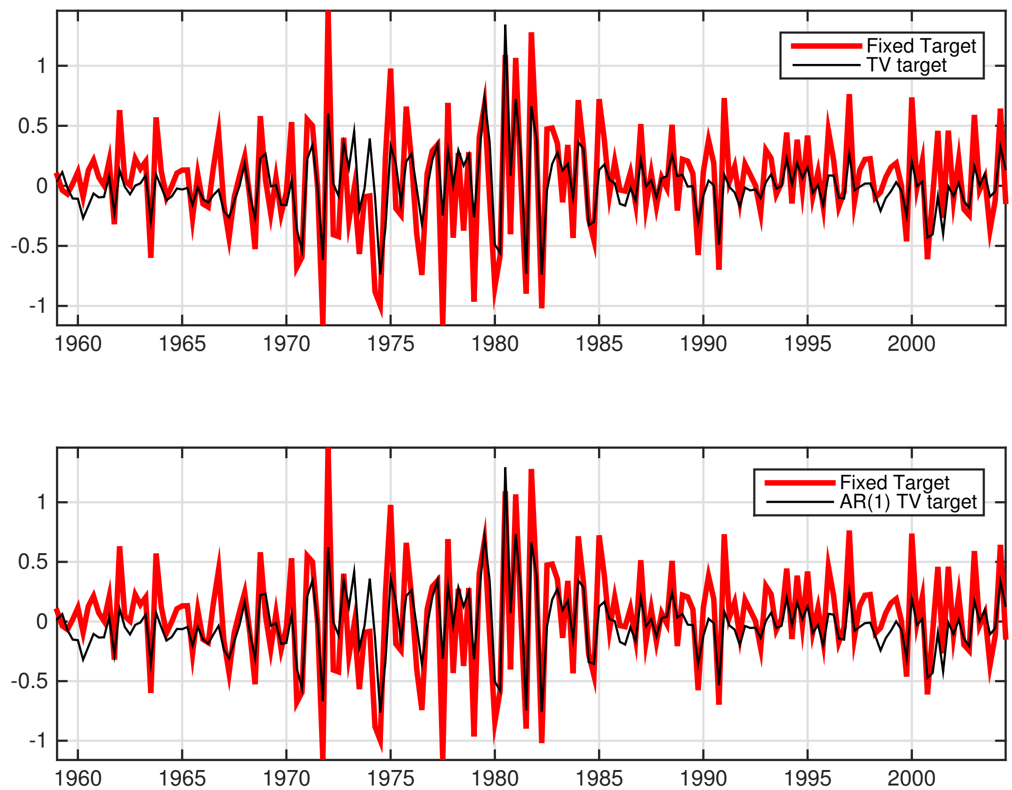
4.1.1. Exogenous shocks to the interest rate

To quantify the impact of a time-varying inflation target on the behaviour of the exogenous monetary policy shocks, I compare the time series properties of the exogenous monetary policy shocks generated by a fixed target model with this series, generated under a time varying inflation target model. First, I focus on comparing the variance of the raw series for the policy shocks generated under both specifications of the time-varying inflation target, with the series generated under a fixed inflation target model. Second, to compare the variance and the evolution of these three series over time, I estimate a stochastic volatility model. Third, I take the variance decomposition of exogenous monetary policy shocks to the variation in inflation, output, hours and interest rate based on a fixed target model, and compare the variation of these variables under the same shock estimated in a time-varying inflation target model.

A comparison of the raw series for the exogenous monetary policy shocks generated across the three models suggests that including the inflation target considerably reduces the variance of the exogenous monetary policy shocks. In my framework, roughly 47% of the volatility in monetary policy shocks could be attributed to a time-varying inflation target, with this reduction robust across various specifications of the inflation target.[14] The time-varying inflation target model explains approximately 60% volatility of the exogenous monetary policy shocks in the pre-Volcker period, suggesting that a large proportion of exogenous shocks observed during the period could be attributed to changes in a time-varying inflation target.

The largest reduction in the volatility of exogenous monetary policy shocks occurs during the 1973 and between the 1980 - 1982 time period, corresponding with the dates when the most important policy changes took place, as presented in Boivin (2005). Potentially, the high degree of economic uncertainity during the pre-Volcker period could have caused the FOMC to shift its inflation target frequently, resulting in volatile interest rates. In this context, my results complement the reasons behind the variation in interest rates pointed out by Cook (1988) by suggesting that changes in the inflation target may be responsible for some of the important changes in monetary policy during these dates, an extension that is missing from fixed inflation target models. Therefore, the standard identification exercises that use a fixed target model to estimate monetary policy shocks may have overestimated the variance, and the contribution of monetary policy shocks to the macroeconomic dynamics (see, for example, Christiano et al. (2005), Gali (2009) and Smets and Wouters (2007)). These results are plotted in Figure 9.

[14]Importantly, this reduction is much larger then the outcome under other misspecifications in the monetary policy rule considered in the appendix.



This figure plots traditional and pure monetary policy shocks. Monetary policy shocks in the top panel represent the residual from an inflation target driven by structural shocks, while the second panel represent the residuals from the inflation target following an AR(1) process. The solid red lines plot exogenous monetary policy shocks based on a fixed inflation target model.

Second, Justiniano and Primiceri (2008) suggests that structural shocks may vary in size over time, especially when comparing the period before and after the Great Moderation. To align my findings with theirs, I examine whether shocks to the time-varying inflation target correlate with the timing of exogenous shocks to the interest rate., both of which are allowed to vary over time. I use the generated series of the exogenous shocks to the interest rate under a fixed inflation target model, and under the two time-varying inflation target models, to estimate an unobserved components model with moving average volatility. For comparison, I also estimate a model using the series of the shocks to the inflation target. I use the standard Gibbs sampler with 200,000 draws from the posterior distribution, after a burn-in period of 10,000. Using this technique I estimate the following specification:

$$j_t = \epsilon_t^j \tag{18}$$

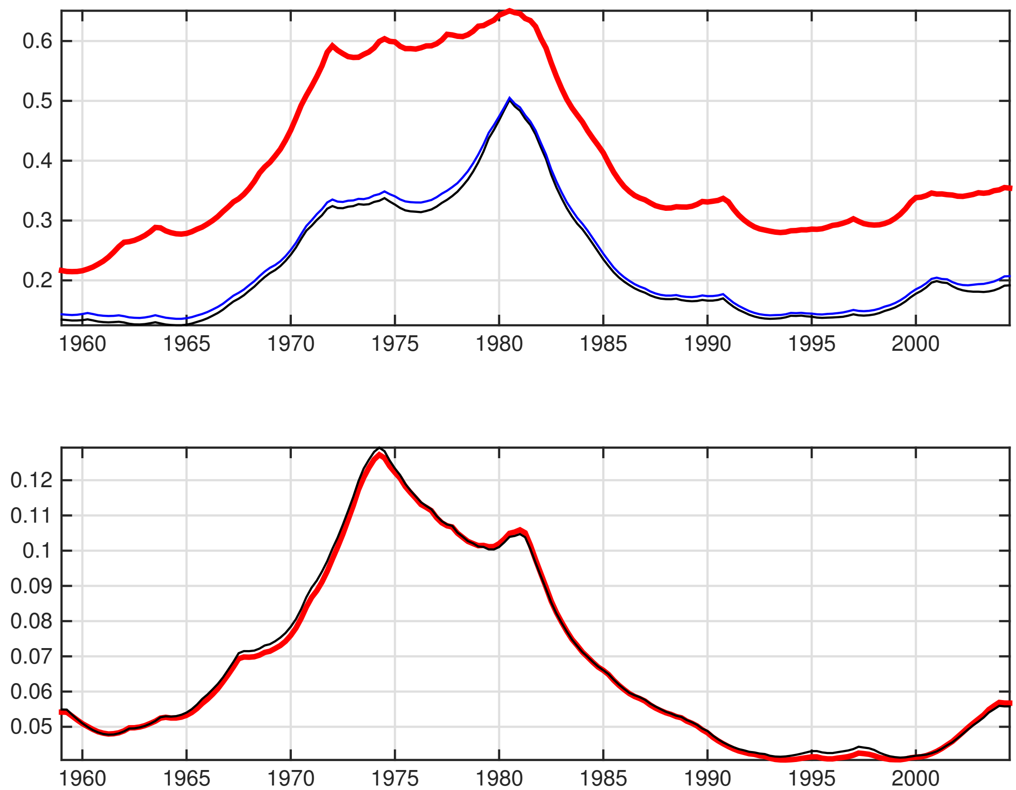
$$\epsilon_t^j = \mu + \psi_1 u_{t-1}, u_{t-1} \sim N(0, e^{h_t}) \tag{19}$$

$$h_t = \mu_h + \phi_h(h_{t-1} - \mu_h) + \epsilon_t^h, \epsilon_t^h \sim N(0, \sigma_h^2) \tag{20}$$

where ϵ_t^j is the time series for the shocks, and $|\phi_h| < 1$. The errors u_t and ϵ_t^h are independent of each other for all leads and lags.[15]

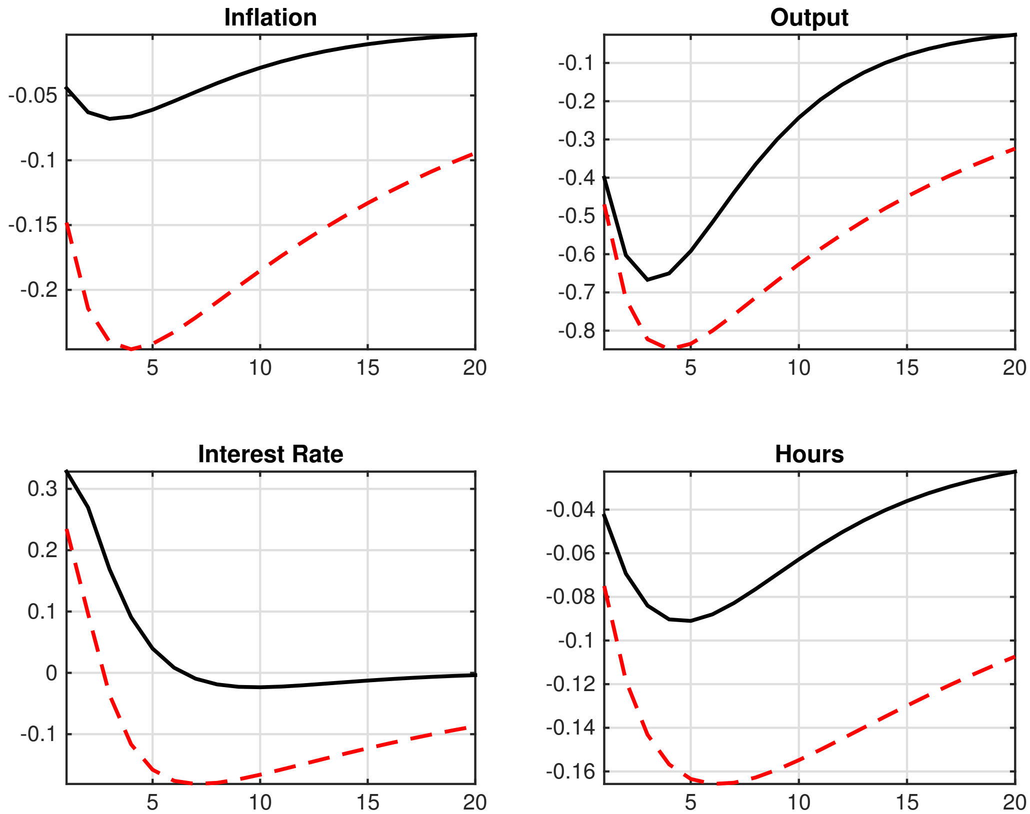
Figure 10 plots the results generated by this model. Estimates from the stochastic volatility model suggest that the variance of exogenous shocks to the interest rate under a fixed inflation target model gradually rises from 1960 through to 1972, remaining large till the early 1980s, and falls sharply from the early 1980s. This is line with the findings presented in Justiniano and Primiceri (2008) who have highlighted the high variance of these shocks during the pre-Volcker period. The time-varying variance of the inflation target follows a similar pattern, with the largest rise coming in the first half of the 1970s, and gradually falling during Volcker's disinflation. This exercise suggests that shocks to the inflation target were most volatile during the 1973 through to 1978 period and 1980 through to 1981 period. These dates correspond to the findings presented in Justiniano and Primiceri (2008), Boivin (2005) and Romer and Romer (1989), and the most important changes in the inflation target seem to largely explain important changes in the interest rate. Since these two shocks are, by construction, orthogonal in the model, this finding justifies that the exogenous monetary policy shock may be misidentified and biased, and shocks to the inflation target may explain a lot of variation attributed to exogenous monetary policy shocks. Therefore, this framework presents a novel contribution to the characterization of changes in monetary policy, which has traditionally been attributed to exogenous and unexplained changes in the reaction function.

[15] Further details of estimating this process can be found in Chan (2013).



This figure plots traditional and pure monetary policy shocks in a stochastic volatility setting. The first panel plots the time-varying series of the exogenous shocks to the interest rate (red line), and exogenous shocks under a time-varying inflation target model. The second panel plots the time-varying variance of exogenous shocks to the inflation target (blue line).

Third, in order to compare the behavior of exogenous interest rate changes generated by a fixed inflation target model with those generated by a time-varying inflation target model, I compare the decomposition of variance and the dynamic responses of inflation, output, labour hours and interest rates. I simulate the model with estimates of monetary policy shocks generated from the fixed inflation target model, and compare with simulations of the model calibrated with results from the time-varying inflation target model, while fixing the structure and the behavioural side of the economy. Simply put, the only difference between the two models I compare is the parameterization of the monetary policy shocks. Figure 11 shows the effect on inflation, output and hours and interest rate, simulated with the purified exogenous interest rate movements and traditional exogenous interest rate shocks.



This figure plots the impulse responses of inflation, output, interest rates and hours to a an exogenous shock to the interest rate. The red dotted lines represent IRF's of a traditional monetary policy shock as estimated by a model with a fixed inflation target. The solid black lines represent IRFs of a traditional monetary policy shock as estimated by a model with a time-varying inflation target.

The impulse response of inflation, output, hours and interest rate to exogenous monetary policy shocks estimated from a time-varying inflation target model suggest a damper response, compared to the response of these variables generated by an exogenous monetary policy shock estimated from a fixed inflation target model. This is due to the considerable lower volatility of the exogenous shocks under the time-varying target model, causing inflation, interest rate and hours to fall by less as compared to their movement under a fixed target model. The hump shaped response of output remains intact and falls by less under the purified exogenous interest rate shocks, returning to steady state quickly. The decomposition of variance in tables 8 and 9 suggests that the reduction in volatility of the exogenous interest rate shocks leads to a 12% lower response in interest rate, which causes a fall of 27% in hours, 30% in inflation and around 24% in output.

Table 7: Variance decomposition: Fixed target model

Variable	ϵ_t^a	ϵ_t^b	ϵ_t^g	ϵ_t^i	ϵ_t^r	ϵ_t^p	ϵ_t^w
Hours	5.55	1.92	7.56	7.77	1.78	15.18	60.25
Interest Rate	3.71	1.99	1.52	12.44	15.88	27.39	37.07
Inflation	1.80	0.29	0.37	3.20	2.83	43.00	48.52
Output	14.01	21.98	22.06	20.82	5.40	6.12	9.61

The table presents the variance decomposition of the seven structural shocks to inflation, interest rate, hours and output in the fixed target model.

Table 8: Variance decomposition: Counterfactual

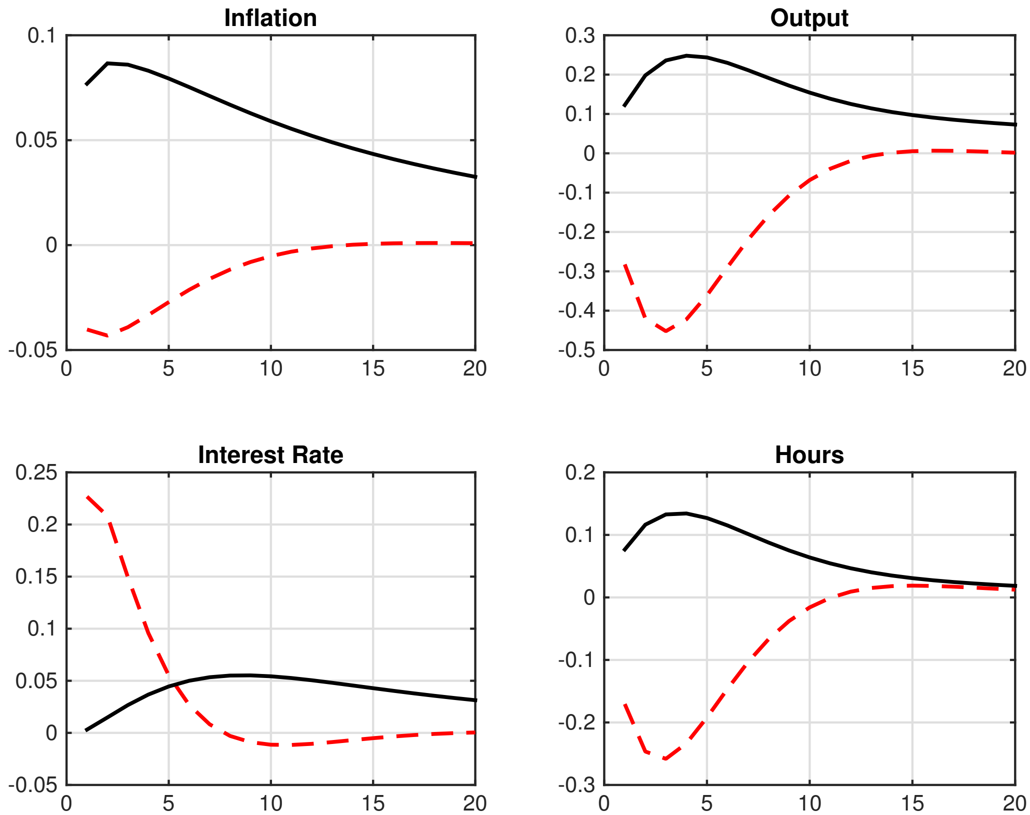
Variable	ϵ_t^a	ϵ_t^b	ϵ_t^g	ϵ_t^i	ϵ_t^r	ϵ_t^p	ϵ_t^w
Hours	5.58	1.93	7.60	7.80	1.30	15.25	60.54
Interest Rate	3.80	2.04	1.55	12.73	13.96	28.01	37.92
Inflation	1.81	0.29	0.37	3.23	2.00	43.36	48.94
Output	14.21	22.29	22.36	21.11	4.08	6.21	9.74

The table presents the variance decomposition of the seven structural shocks to inflation, interest rate, hours and output by calibrating the fixed target model with the parameters obtained from the model with a time varying inflation target.

This section presents evidence that supports the hypothesis that a time-varying inflation target may explain a large portion of the variation attributed to exogenous monetary policy shocks. In this context exogenous monetary policy shocks are largely contaminated by changes in the inflation target, and therefore overestimate the true effects of exogenous monetary policy shocks in a macroeconomic model. Critically, the behaviour of the time-varying shocks to the inflation target corresponds with the behaviour of the shocks to the exogenous interest rates. This is especially true around the periods corresponding to the dates when the largest changes in monetary policy took place as identified in the existing literature. These findings call for a reevaluation of the macroeconomic effects of exogenous shocks in a DSGE model by considering time-varying reaction functions as further clarifying the behaviour of monetary policy.

*4.1.2. **Exogenous shocks to the inflation target***

Having highlighted the impact of the time-varying inflation target on the properties of the exogenous changes in the interest rate, I focus on the impact of this shock on macroeconomic dynamics. Figure 12 compares the response of interest rate, inflation, output and hours under the estimated shock to the inflation target with a shock to the interest rate.



The figure represents the IRF's of traditional monetary policy shocks(red dotted line) and shocks to the inflation target(black solid line)

A positive shock to the inflation target initially raises inflation, interest rates, output and hours. In the first 8 periods, inflation rises by 7-basis-points, output by 21-basis-points interest rates by 3-basis-points and hours by 11-basis-points. Since agents in this model are unable to distinguish between transitory exogenous interest rate shocks and persistent exogenous inflation target shocks in the short run, the perceived inflation target deviates from the central bank's chosen target. This leads to an unanchoring of inflation expectations, causing inflation to rise persistently and interest rates to start rising. Due to the forward-looking nature of inflation, economic agents expect higher inflation in the next period, some of which is partially cancelled by the past indexation in the Phillips curve. Since the shock is very persistent, inflation continues to rise, until interest rates rise rapidly. This effect causes the inflation response to be hump-shaped. The interest rate response by the monetary authority is not sufficient to close this inflation gap, since inflation expectations have been unanchored. Hours behave analogously to inflation in this model: firms, while setting wages, are forward looking but due to the presence of some partial indexation to the past wage rates display a hump-shaped response. Since the change in policy is implemented gradually and expectations have time to adjust, the output effects of the change in inflation are much smaller. Even after 20 periods, all variables are above steady state: inflation is still 3 basis points above steady state, interest rates are 3-basis-points above steady state, output is 7-basis-points above steady state and hours are 1.8-basis-points above steady state. While inflation expectations become relatively more anchored as compared to the first 8 periods as the inflation target returns to steady state, the model suggests that inflation expectations are not fully anchored even after 20 periods, due to the permanent nature of the shock to the inflation target.

My findings suggest that the propagation effect of a shock to the inflation target is very different compared to the effect of an exogenous interest rate shock, and causes a hump-shaped response of inflation, output, hours and the interest rate. As private sector inflation forecasts in the United States (where monetary policy is not guided by an inflation target) are highly correlated with a moving average of lagged inflation, while this correlation is essentially zero in a number of countries with formal inflation targets (Levin et al. (2004)), my findings suggest that the output costs of changing an inflation target may be very low. This issue is examined in detail in the last section. Moreover, since the shock to the inflation target is implemented gradually, it may reconcile evidence of the 'price puzzle' introduced in Eichenbaum (1992). Therefore, my results suggest that a price puzzle may arise since these two policy shocks are often combined.[16]

4.2. Subsample estimates and the Great Moderation

In this section, I assess the contribution of the shock to the inflation target on the high macroeconomic volatility experienced by post-war U.S. This exercise is motivated by empirical evidence presented in Stock and Watson (2002) who identify a large decline in the volatility of aggregate economic activity, employment and inflation since the early 1980s. Previous studies offer several potential explanations for this "Great Moderation." Some studies point to evidence that output volatility fell more than sales volatility, highlighting

[16] My framework and analysis is very different from the one presented Bache and Leitemo (2008), who estimate a VAR model based on artificial data generated from a stylized model. My framework uses a more representative model of the U.S. economy, and relies on estimated parameters rather than a parameterized model, and therefore paints a more realistic picture of the role of policy shocks compared to other structural shocks observed in the U.S. dynamics.

the potential role of better inventory control methods (see, for example, Kahn et al. (2002)). Another line of research stresses "good luck" in the form of smaller exogenous shocks (see, for example, Stock and Watson (2002)). Better monetary policy played an important role in the reduction in volatility, and therefore moving to a 'better' monetary policy regime has large welfare effects (see, for example, Clarida et al. (1998a)).[17] However, my framework generalizes better policy to include a stable inflation target observed during the post-Volcker era.

My estimates suggest that the process for the inflation target is more persistent, compared to a standard exogenous shock to the interest rate. Moreover, shocks to the inflation target are estimated to be almost twice as volatile during the sample from 1959 through to 1979:II, compared to the period 1984 through to 2004:IV. This channel may have played an important role in generating the excess volatility observed during the former time period. To make a fair comparison with the baseline Smets and Wouters (2007) model, I compare the standard deviation of inflation and output growth in the data for the entire time period, by computing the theoretical moments of the model. This allows me to first compare the fit of my extended model with actual dynamics observed in the data, before proceeding with policy counterfactuals. In the baseline case, the model is also estimated for 1959 through to 2004:IV. I re-estimate the model for the 1966 through to 2004:IV time period in oder to compare with the Smets and Wouters (2007) sample. Table 10 summarizes these results.

Table 9: Model Fit

Variable	Data	SW	TVE	TV
Inflation	0.61 - 0.62	0.57	0.61	0.51
Output	0.89 - 0.85	0.94	1.45	1.28

The table compares the fit of the estimated model with the data, the Smets and Wouters (2007) model and the time-varying inflation target model with different sample selection. Under the data column, the first value presents the value for the 1959:I - 2004:IV sample, while the second value presents the value for the 1966:I - 2004:IV samples. SW is the baseline Smets and Wouters (2007) model. TVE is the time-varying inflation target model for the 1959:I - 2004:IV sample, while TV is the time-varying inflation target model for the 1966:I - 2004:IV samples.

My results suggest that the extended model fits the data on inflation better from 1959:I through to 2004:IV compared to the results found in Smets and Wouters (2007), which fit the data on inflation better for the 1966:I through to the 2004:IV period. To compare the

[17] Summers (2005) perform a cross country analysis which also backs the role of monetary policy in reducing the macroeconomic volatility across countries.

extended subsample with the baseline Smets and Wouters (2007) case, I re-estimate the model and compare the fit for the subsamples from 1959:I to 1979:II, 1966:I through to 1979:II, and from 1984:I - 2004:IV. The extended model improves the fit of inflation for 1959:I through to 1979:II, but both output and inflation volatility are overestimated in the second sample in the time-varying inflation target model. These findings suggest that a time-varying inflation target fits the data better in the first sample, as compared to the second sample, irrespective of the initial date of the first subsample. Therefore, the behaviour of inflation in the first subsample is better matched in the model that includes a time-varying inflation target, and may suggest a possibly important exclusion from current models that analyze this sample. This finding also verifies the evidence suggested by Belaygorod and Dueker (2005), who do not find the inflation target to be important in the post-1984 period.

Table 10: Model Fit: first subsample

Variable	Data	SW	TVE	TV
Inflation	0.69 - 0.55	0.81	0.74	1.07
Output	1.02 - 1.02	1.13	1.7	1.56

The table compares the fit of the estimated model with the data, the Smets and Wouters (2007) model and the time-varying inflation target model with different sample selection. Under the data column, the first value presents the value for the 1959:I - 2004:IV sample, while the second value presents the value for the 1966:I - 2004:IV samples. SW is the baseline Smets and Wouters (2007) model. TVE is the time-varying inflation target model for the 1959:1 - 1979:II sample, while TV is the time-varying inflation target model for the 1966:I - 1979:II sample.

Table 11: Model Fit: second subsample

Variable	Data	SW	TVE
Inflation	0.25	0.34	0.56
Output	0.55	0.73	0.99

The table compares the fit of the estimated model with the data, the Smets and Wouters (2007) model and the the time-varying inflation target model with different sample selection. SW is the baseline Smets and Wouters (2007) model. TVE is the time-varying inflation target model for the 1984:1 - 2004:IV sample.

I use this model to quantify the contribution of the inflation target to the macroeconomic volatility observed during the pre-Volcker era. For the purposes of this exercise, I use the estimation results of the first sample, and discuss the contribution to economic volatility of the various potential sources of disturbances. I quantify the contribution of the economic structure, preceded by the contribution of the volatility of the structural shocks, followed by the contribution of monetary policy to the economic volatility. I add a layer of complication by discussing the consequences for the volatility of the economy if the inflation target had remained as volatile as it was in the first sample, and study the implications by comparing it with a period when the inflation target is estimated to have stabilized, and remained within a narrower band of 1.5 to 2.5%. To estimate the contribution of these counterfactual scenarios, I sequentially replace the structural parameters, the policy parameters, the structural shocks, and exogenous shocks to the inflation target during the first sample, with the estimates of the second sample.[18]

Table 12: Counterfactual Analysis

Variable	Data	TVE	Shocks	Monetary Policy	Inflation Target	Structure
Inflation	0.25	0.5	0.84	0.56	0.78	0.57
Output	0.55	1.1	1.39	1.00	1.00	1.01

The table decomposes the sources of the Great Moderation into the contribution of shocks, monetary policy, inflation target and structural parameters. The first column presents the data for the 1984:1 - 2004:IV sample, with the second column titled TVE presents the model implied theoretical moments for the 1984:1 - 2004:IV sample. The column titled 'Shocks' presents the contribution of structural shocks, if the U.S economy experienced in the 1984:1 - 2004:IV sample experienced the shocks of the 1959:1 - 1979:II sample. The column titled 'Monetary policy' focuses on the contribution of monetary policy to the macroeconomic volatility, while the column 'TVE' isolates the volatility from a time-varying inflation target of the 1959:1 - 1979:II with the second sample. The column on 'Structure' presents the contribution of the transmission mechanism to the Great Moderation.

The results illustrate an important channel of 'bad' monetary policy, one of the reasons behind the increased macroeconomic instability in the first sample. If the target had remained as volatile as it was in the first sample, inflation would have been 39% more volatile. This is close to the estimates suggested in Castelnuovo (2012). This channel suggests that policy mistakes that occurred in the first subsample may also be extended to include volatile endogenous movements in the feedback rule. Moreover, of the total movement in inflation volatility, the feedback effect if the Fed responded to structural shocks contributed to a little less than 2% of the inflation volatility. There are two important consequences of this result. First, even if the model had wrongly rejected the opportunistic approach to disinflation hypothesis, my results suggest that this channel played a minor role in contributing to the macroeconomic volatility of that period. Second, most of the observed volatility in inflation

[18] In order to be consistent with my previous findings, I use the following two subsamples 1959:I - 1979:II, and from 1984:I - 2004:IV for this section.

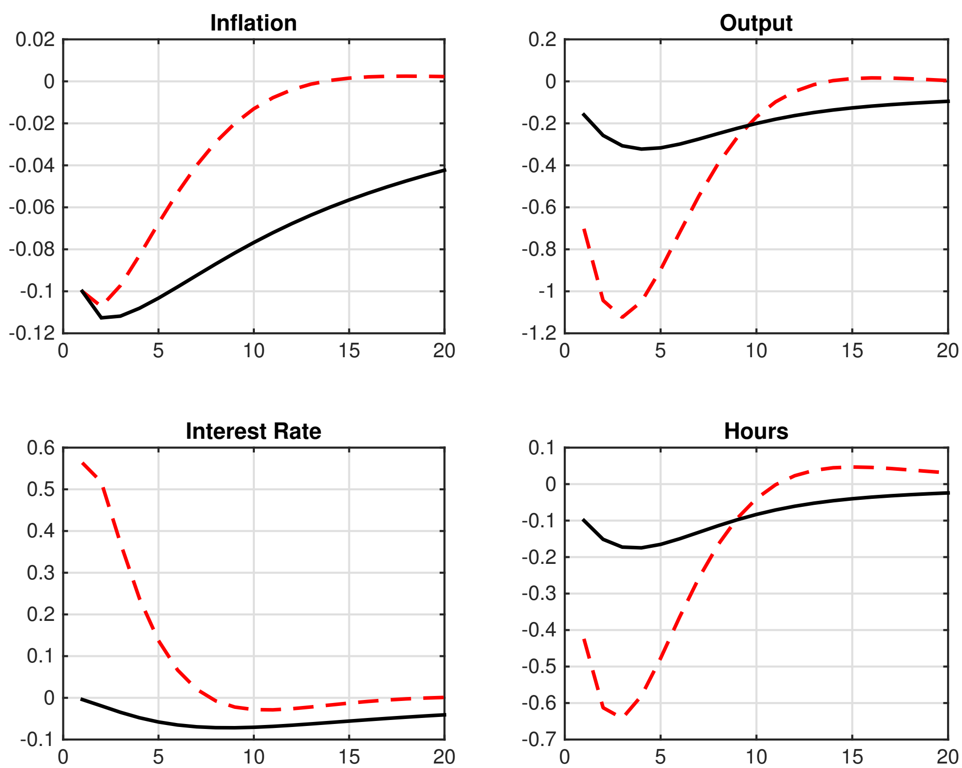
is due to a volatile inflation target, represented by shocks to the inflation target. One can analyze this evidence in a slightly different light: in the first sample, the inflation target was volatility, for the reasons explored in the previous section, lead to an unanchoring of inflation expectations. However, in the second sample the inflation target rarely moved outside a tight range, highlighting the Fed's increased credibility, and the possible reasons behind the anchoring of inflation expectations, supporting the main findings made in Tetlow (2008). In this context, the time-varying systematic policy rule may help account for the apparent rise and fall in economic volatility experienced by the U.S. economy, complementing the findings made in Primiceri (2005).

The monetary authorities' response coefficients to inflation and output, and changes in the structure of the transmission mechanism, play a minor role in the Great Moderation, a result which is similar to the findings in Smets and Wouters (2007). Had structural shocks remained as volatile as they had been in the first sample, inflation would have been 54% more volatile, confirming the evidence found in Sims and Zha (2006), lending further support to the good luck hypothesis as the major explanation for the resulting rise in macroeconomic stability.

4.3. Policy experiment and the sacrifice ratio

In a preceding section, I highlighted that the impact on the economy of changes in monetary policy due to changes in interest rate is different to the impact of changes in the inflation target. These two modes of changing the interest rate could be treated as potentially different tools to achieve a macroeconomic objective. To compare these two shocks, I normalize their effect such that both types of policy changes represent ways to cause disinflation. Specifically, I normalize the effect of the shocks in such a way that both shocks are contractionary, and are of the same size in terms of their effect on inflation. The impulse responses for output, hours and interest rates are multiplied by the same normalizing constant. I use these normalized responses in order to compare the welfare consequences of using these as policy tools. In general this suggests a novel policy perspective on the economic costs of changing the inflation target compared to random perturbations in the interest rate.

In figure 13, I plot the normalized impact of monetary policy shocks and the normalized impact of shocks to the inflation target. Inflation is normalized to be -10-basis-points on impact. Under an exogenous shock to the inflation target, inflation falls for four periods before gradually rising towards steady state, compared to a one period fall before moving towards steady state under a shock to the exogenous interest rate. The shock is so persistent that even in the twenty periods considered, inflation does not return to steady state, compared to the 12 periods it takes to return to steady state under an exogenous shock to the interest rate. The corresponding decline in output and hours is higher under a exogenous change to the interest rate. Under a exogenous change in the interest rate, output falls by 80-basis-points in the first 8 periods, returning to zero in 15 periods. Under a shock to the inflation target, output falls to around 27-basis-points, but is 9 basis points below steady state even after 20 periods. This result differes from Ireland (2005), who finds that the effect on output of a shock to the inflation target is largely transitory. Based on these results, a shock to the inflation target induces a gradual change in the interest rate, with the exogenous shock producing a sharp rise, and fall to steady state values. Labor hours fall by 44-basis-point under a movement in the exogenous interest rate, and only fall by 14-basis-point under a shock to the inflation target. Similar to output, hours worked return to steady state after about 10 periods under a discretionary interest rate shock, while remaining persistently low at 2.5-basis-points below steady state after a shock to the inflation target.



The figure represents impulse response functions of normalised traditional monetary policy shocks (red dotted line) and shocks to the inflation target (black solid line).

Since the dynamic response of output, labor hours and inflation to a shock to the inflation target is very different from an exogenous shock to the interest rate, each type of policy implies economic trade-offs. I tabulate these trade-offs by comparing the sacrifice ratio implied by each type of shock. I calculate the sacrifice ratio of the two monetary policy shocks by dividing the cumulative response of output to each shock by the cumulative response of inflation. For a discretionary interest rate shock, the sacrifice ratio is calculated to be around 11.4, while the sacrifice ratio is calculated to be 2.5 for the discretionary inflation target shock. In lost-output terms, it costs 4.5 times more, when using discretionary interest rate changes as compared to discretionary inflation target changes, to cause disinflation. In order to gauge the change in labor hours, I find a sacrifice ratio for the hours worked by dividing the cumulative response of change in hours by response of inflation. For a discretionary interest rate shock, the sacrifice ratio is calculated to be around 5.4, for the discretionary inflation target shock, the sacrifice ratio is calculated to be 1.14. It costs 4.7 times more worker hours to decrease inflation by the same amount when using discretionary interest rate changes, compared to discretionary inflation target changes.

First, the sacrifice ratios contribute to the findings made in Fuhrer (1994), Wascher et al. (1999), Ball and Reyes (2007) and Cecchetti and Rich (1999) who find different estimates of the sacrifice ratio. My framework suggests that the differences in sacrifice ratios may reflect the different impact of the two types of monetary policy changes on macroeconomic welfare, contributing to reconciling the variability in the range of the sacrifice ratio tabulated across these studies. Second, persistent changes in endogenous monetary policy have lower repercussions on output and hours, as compared to transitory and surprising changes in monetary policy. This evidence supports the view that to achieve a certain macroeconomic objective, adjusting to a new (unannounced) inflation target is better than unannounced monetary policy changes reflected in discretionary changes in the interest rate, extending the literature on changes in the inflation target (Svensson (2010)).

5. Conclusion

In this paper I decomposed deviations of the Federal funds rate from a Taylor type monetary policy rule into exogenous monetary policy shocks and a time-varying inflation target. In my framework, exogenous changes in the interest rate could be due to changes in a time-varying inflation target causing exogenous monetary policy shocks to be misidentified. This could lead the model to wrongly attribute business cycle fluctuations to exogenous changes in monetary policy, when they are in fact due to changes in the inflation target. My results suggest that the inclusion of the time-varying inflation target helps further clarify the contribution of exogenous changes in policy. It also plays an important role in contributing to business cycle fluctuations, generating macroeconomic volatility, and has important implications for policy prescriptions.

Using an extrapolated series for the inflation target to estimate a large business cycle model of the U.S. with a stochastic inflation target, explains almost half of the model-implied volatility associated with monetary policy shocks. It also confirms evidence of a large fall in variance of exogenous monetary policy shocks, compared to a fixed inflation target model. The peak in the variance of exogenous monetary policy shocks occurs during the peak in the variance of the shocks to the inflation target extending the findings in Justiniano and Primiceri (2008), Christiano et al. (2005), Gali (2009) and Smets and Wouters (2007). The time-varying inflation target points to an important source of changes in monetary policy around the dates identified in Boivin (2005). Accordingly, I show that that a model with a fixed target overestimates the effects of exogenous monetary policy shocks, which are calculated to have been attributed with excess of 12% volatility in interest rate, 27% volatility in labor hours, 30% volatility in inflation and around 24% additional volatility in output.

This paper finds that almost 39% of the volatility in inflation may be attributed to the time-varying inflation target during the Great Inflation, suggesting a novel channel to interpret bad monetary policy, extending the findings presented in Clarida et al. (1998a), Summers (2005) and Taylor (1999), Primiceri (2005). My framework suggests that one reason inflation might have been less volatile during the Great Moderation may be due to the time-varying inflation target bounded within a narrow range, supporting the main results presented in Tetlow (2008). Changes in the inflation target and exogenous shocks to the federal funds rate, are shown to impact the economy differently. To achieve the same macroeconomic objectives, changing the inflation target may suggest a considerably lower sacrifice ratio, compared to transitory perturbations in the interest rate,. It costs 4.5 times more when using exogenous interest rate changes compared to exogenous inflation target changes, to cause disinflation, contributing to the findings of Fuhrer (1994), Wascher et al. (1999), Ball and Reyes (2007) and Cecchetti and Rich (1999).

A natural extension of this project is to explore the actual causes of the time-varying inflation target, possibly using the FOMC transcripts. Moreover one can allow both the targets and the policy parameters to vary over time, and study the role of each in explaining exogenous policy shocks in a non-linear setting. These are issues to be explored in future work.

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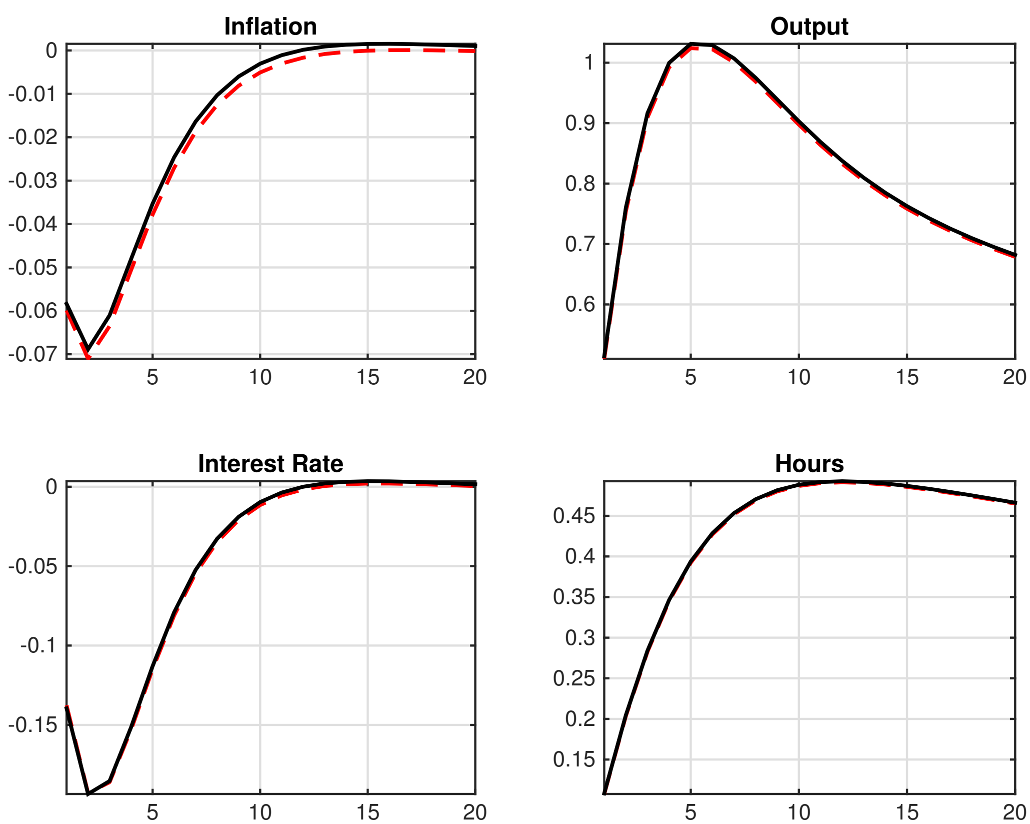
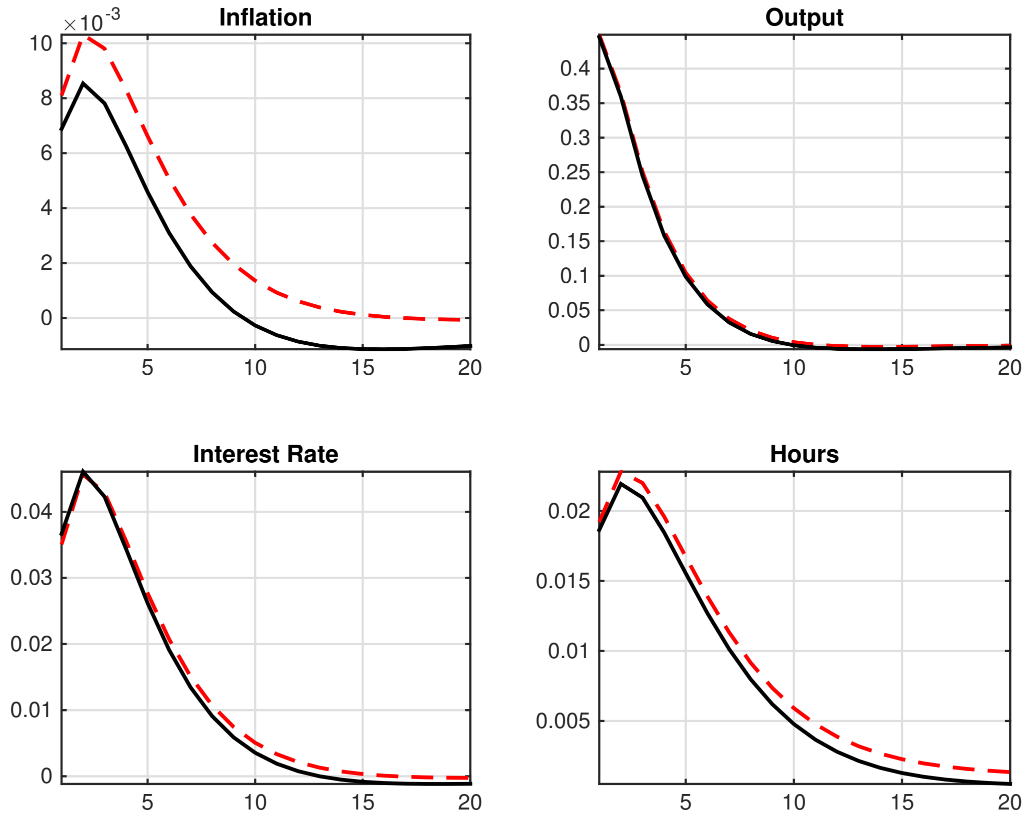
A. For the online appendix

A.1. Dynamic responses

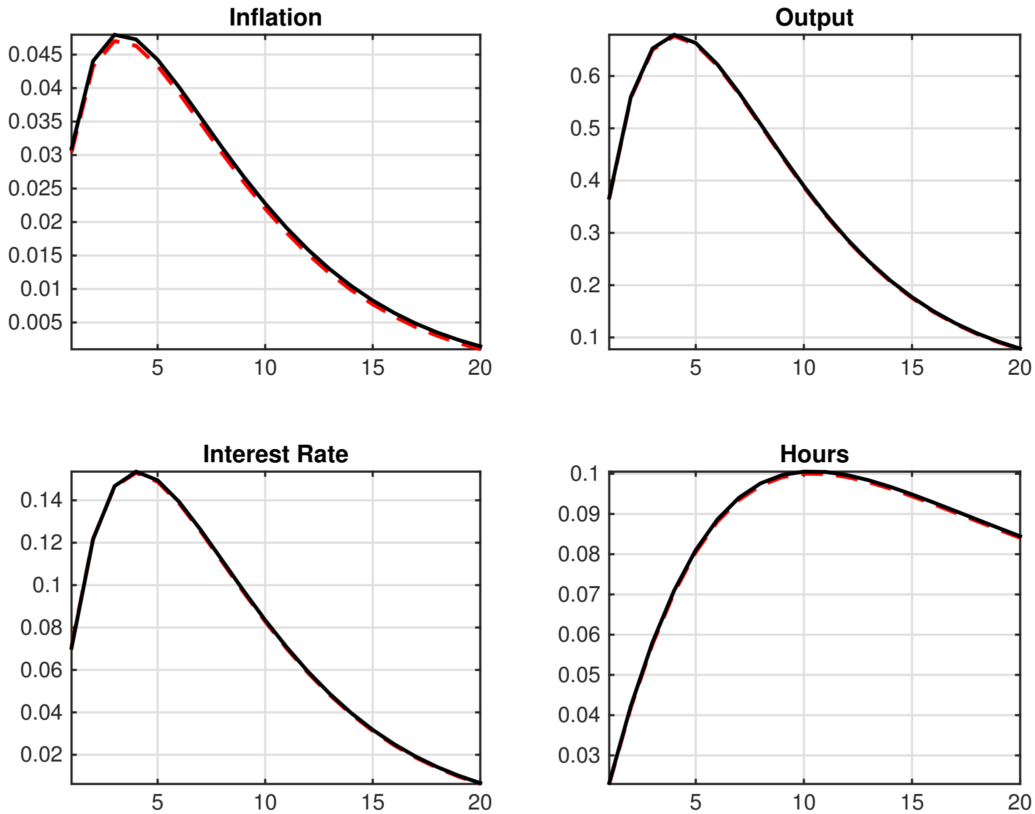
Figures 1 through to 7 summarise the impact of the structural shocks on inflation, output, interest rate and hours under a fixed target model, and a time-varying target model. Since the estimated structural shocks are remarkably similar under both models, these responses are very similar across both specifications of the inflation target. Since the AR(1) time-varying inflation target best fits the data, I only focus on this specification. I compare the impact of these shocks with a fixed inflation target model. Since the estimated models have the same structure, and the same estimates of the structural shocks, the impact on inflation, output, interest rate and labor hours are very similar.



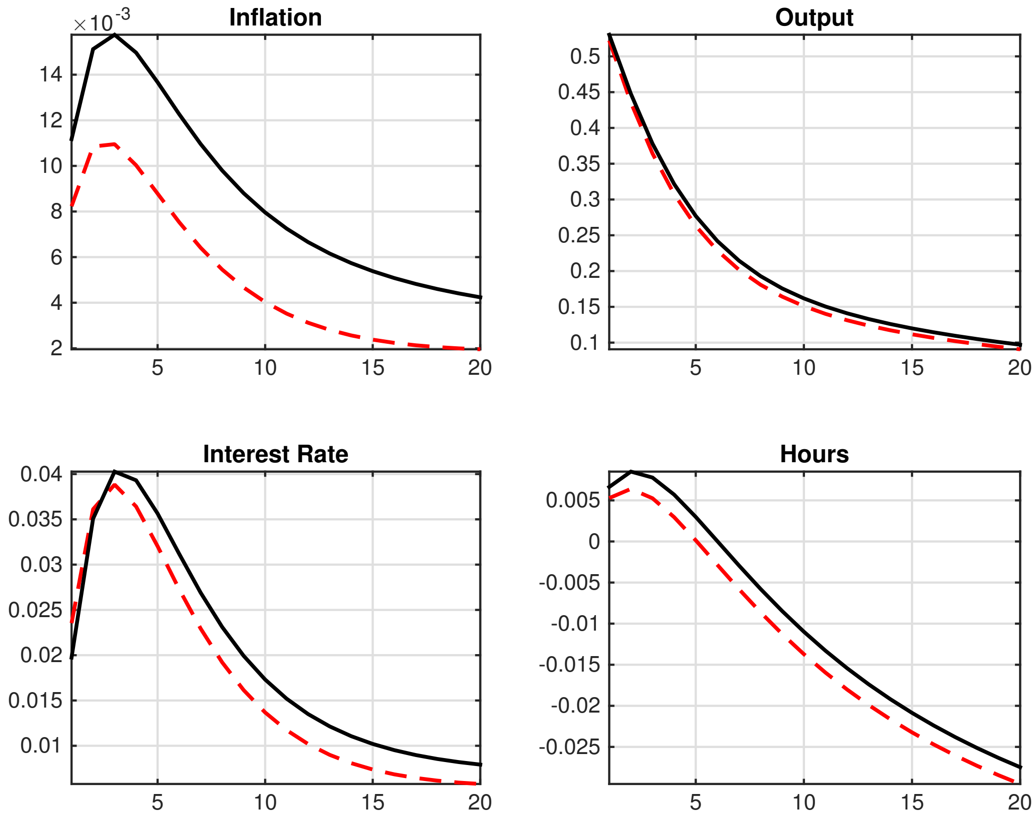
This figure plots the impulse response of inflation, output, hours and interest rate to a **productivity shock**. The red dotted lines represent IRF's under a fixed inflation target, and the solid black line represents IRF's based on a time-varying inflation target.



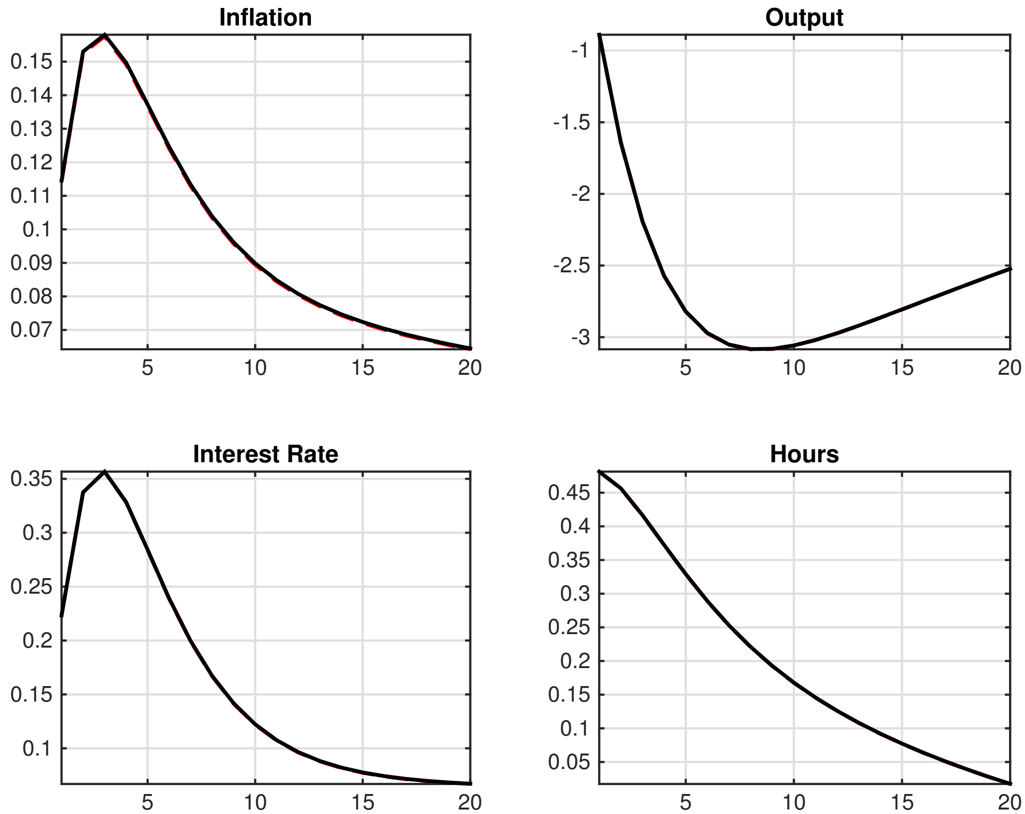
This figure plots the impulse response of inflation, output, hours and interest rate to an **asset premium shock**. The red dotted lines represent IRF's under a fixed inflation target, and the solid black line represents IRF's based on a time-varying inflation target.



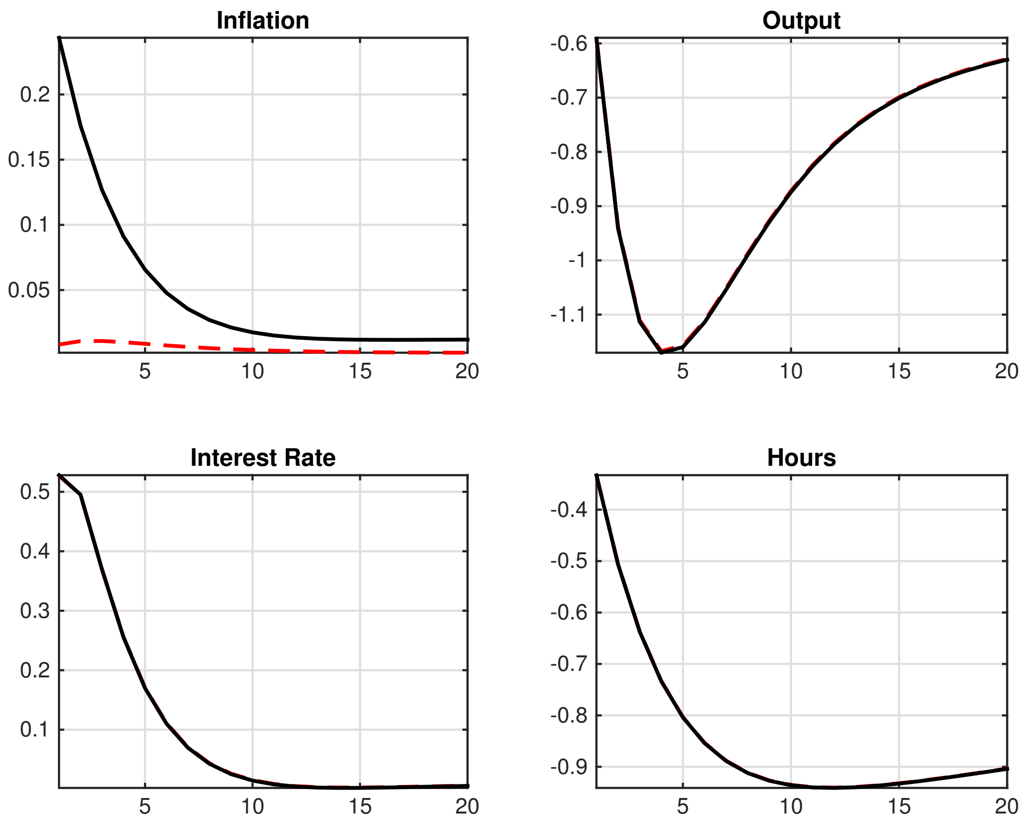
This figure plots the impulse response of inflation, output, hours and interest rate to an **investment-specific technology shock**. The red dotted lines represent IRF's under a fixed inflation target, and the solid black line represents IRF's based on a time-varying inflation target.



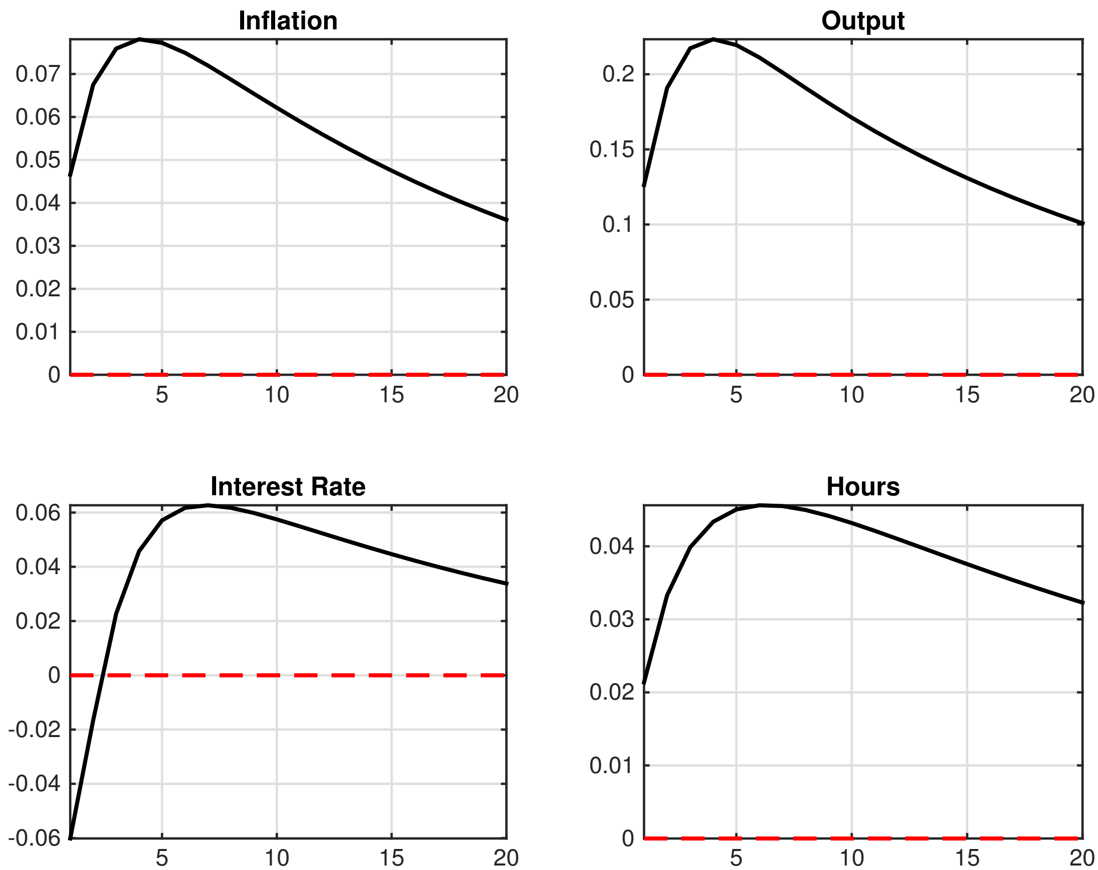
This figure plots the impulse response of inflation, output, hours and interest rate to a **demand shock**. The red dotted lines represent IRF's under a fixed inflation target, and the solid black line represents IRF's based on a time-varying inflation target.



This figure plots the impulse response of inflation, output, hours and interest rate to a **wage mak-up shock**. The red dotted lines represent IRF's under a fixed inflation target, and the solid black line represents IRF's based on a time-varying inflation target.



This figure plots the impulse response of inflation, output, hours and interest rate to a **supply shock**. The red dotted lines represent IRF's under a fixed inflation target, and the solid black line represents IRF's based on a time-varying inflation target.



The solid black line represents impulse response of inflation, output, hours and interest rate to a **shock to the inflation target.**

A.2. Robustness across different series for the inflation target

Table 13: Model-Fit comparison, 1959q1 - 2004q3

	Model 1		Model 2		Model 3		Model 4		Model 5	
Parameter	Fixed	TV	Fixed	TV	Fixed	TV	Fixed	TV	Fixed	TV
ϕ_π	3	3	2	2	4	4	2.5	2.5	3	3
ϕ_y	0.05	0.05	0.1	0.1	0.05	0.05	0.1	0.1	0.05	0.05
ρ_r	0.25	0.25	0.05	0.05	0.25	0.25	0.1	0.1	0.75	0.75
ρ_v	0.32	0.24	0.29	0.18	0.90	0.21	0.38	0.27	0.41	0.38
σ_v	0.26	0.25	0.25	0.24	0.54	0.26	0.26	0.25	0.27	0.32
δ_a	-	0.0058	-	0.0137	-	0.0033	-	0.0028	-	-0.0005
δ_g	-	0.0055	-	0.0051	-	0.0090	-	-0.0036	-	-0.0013
δ_b	-	-0.0068	-	-0.0018	-	0.0026	-	-0.0109	-	0.0009
δ_i	-	-0.0030	-	0.0014	-	-0.0026	-	-0.0115	-	-0.0023
δ_w	-	-0.0015	-	-0.0157	-	0.0035	-	-0.0117	-	-0.0091
δ_p^p	-	-0.0083	-	-0.009	-	-0.0055	-	-0.0068	-	-0.0042
LL	-1111.8	-921.27	-1090.2	-922.07	-1148.7	-933.05	-1112.68	-929.63	-1114.4	-1035.6

The table presents the estimated values of the monetary policy parameters using different series for the inflation target, and compares it with a fixed inflation target. The first panel corresponds to the value of the policy parameters which is used to extrapolate the inflation target in section 2. The second panel corresponds to values of the process for monetary policy shocks under fixed and time varying inflation target models. The third panel shows the estimated values of the response of the monetary authority to structural shocks, while the last panel presents the marginal density of the model using Geweke (1999) modified harmonic mean estimator.

A.3. Robustness across other specifications

To deal with potential misspecification in the Fed's feedback rule such as other ways structural may enter the feedback rule independently of the target, I estimate the complete model with different specifications of the feedback rule. For the three baseline cases as before, I estimate a model with a fixed inflation target a time-varying inflation target driven by structural shocks, and an AR(1) target model. The model is further estimated using six possible misspecifications in the feedback rule; first, when the inflation target is constant and there may be an omitted variable, θ_t, which is driven by the six structural shocks, and second when we have an AR(1) time-varying inflation target, with θ_t assumed to be driven by the six structural shocks. Third, the model is estimated using the unfiltered series, i.e., the residual from the feedback rule, as discuss in section 2. The motivation for including a noisy target is discussed in Tetlow (2000), who suggests that the implicit inflation target may have been subject to considerable randomness. Different combinations of structural shocks are allowed to enter in the time-varying inflation target, as potential misspecifications cases four and five. Finally an ARMA(1,1) process for the inflation target in the otherwise standard feedback rule is also estimated. Table 13 summarizes the results from the different specifications of the inflation target.

Fixed target model Estimate the full model with a fixed inflation target.

Time Varying target model Estimate the full model with a time-varying inflation target, with the inflation target driven by the six structural shocks as described in section 3.

AR(1) target Estimate the case the movement in the target was exogenous and not driven by the Central Bank responding to structural shocks.

$$\pi_t^T = \rho_\pi \pi_{t-1}^T + \epsilon_\pi \tag{21}$$

Comparison with misspecified Taylor Rule - (a) A potential misspecification in the Taylor rule is considered, where θ_t is driven by the 6 structural shocks, and is identified as the noisy component of the Taylor rule, using the Kalman filter, as discussed in section 2, and the inflation target is kept fixed.

$$i_t = \rho_r i_{t-1} + (1 - \rho_r)(\phi_\pi \pi_t + \phi_y \tilde{y}_t) + \theta_t + \upsilon_t \tag{22}$$

Comparison with misspecified Taylor Rule - (b)

$$i_t = \rho_r i_{t-1} + (1-\rho_r)(\phi_\pi(\pi_t - \pi_t^T) + \phi_y \tilde{y}_t) + \theta_t + v_t \tag{23}$$

As before θ_t is driven by the 6 structural shocks in the model, and the data series is identified as the noisy component of the Taylor rule, using the Kalman filter, and the movement in the inflation target is now exogenous following an AR(1) process, as shown in equation 21 and therefore not driven by the Central Bank responding to structural shocks vis a via the inflation target.

Model with noisy target I use the unfiltered series for the inflation target, and allow it to be a function of the six structural shocks in the model.

Model with different specification of Target - (a) The target is set to evolve as a function of just the real structural shocks in the economy, productivity, government spending and investment and finance premium shocks.

Model with different specification of Target - (b) The target is set to evolve as a function of just the nominal structural shocks in the economy, inflation and wage shocks.

Model with ARMA(1,1) Target The target is introduced as an ARMA(1,1) process.

$$\pi_t^T = \rho_\pi \pi_{t-1}^T + \eta_t^\pi + \rho_{\pi^a} \eta_{t-1}^\pi \tag{24}$$

While the results strongly favour a model with a time-varying inflation target, as compared to a model with a fixed inflation target, the Bayesian Information Criterion (BIC) suggests that the model with an AR(1) inflation target is preferred over a model with an endogenous inflation target, that is, one driven by the six structural shocks. This result back the claim made by Ireland (2005), who show that there is little evidence to suggest that the movement in inflation target was due to structural shocks. At the same time, the model favours a time-varying inflation target as compared to a fixed target model, which has important consequences for monetary policy shocks, as well as volatility in the economy, as discussed in section 4 and 5. A model with an AR(1) inflation target and an omitted variable θ_t driven by the six structural shocks does better than a fixed target model, which seems to suggest that somehow the structural shocks may enter the feedback rule, though independently of the inflation target. The model with just an omitted variable and a noisy target rank last as suggested by the Bayesian Information Criterion (BIC).

A.4. Data

I use seven key macro-economic quarterly US time series as observable variables: the log difference of real GDP, real consumption, real investment and the real wage, log hours worked, the log difference of the GDP deflator and the federal funds rate. All data are available from the FRED database. The data for the inflation target is extrapolated in section 2, and the log difference is used in the estimation.

A.5. Estimation

The following section describes the algorithm used to compute the MH procedure:

1. Choose a starting value or prior for our parameters Θ. For the fixed target model, Θ is composed of 36 parameters, and Θ for the time-varying inflation target models (AR(1) and structural) compose of 39 and 45 parameters respectively.

2. Draw Θ^* from $J_t(\Theta^*|\Theta^{t-1})$. The jumping distribution $J_t(\Theta^*|\Theta^{t-1})$ determines where we move to in the next iteration of the Markov chain and contains the support of the posterior.

3. Compute acceptance ratio r, according to:

$$r = \frac{p(\Theta^*|y)/J_t(\Theta^*|\Theta^{t-1})}{p(\Theta^{t-1}|y)/J_t(\Theta^{t-1}|\Theta^*)} \tag{25}$$

   If our candidate draw has higher probability than our current draw, then our candidate is better so we definitely accept it. Otherwise, our candidate is accepted according to the ratio of the probabilities of the candidate and current draws.

4. Accept Θ^* as Θ^t with probability $min(r, 1)$. If Θ^* is not accepted, then $\Theta^t = \Theta^{t-1}$. Candidate draws with higher density than the current draw are always accepted.

A sample of 250000 draws was created, with 5 MH chains, and the first 20% of the sample was rejected. The model is estimated over the full sample period from 1959:1 till 2004:4[19]

[19] In Section 5.4 we estimate the model over two sub periods (1959:1-1979:2 and 1984:1- 2004:4) in order to investigate the stability of the estimated parameters.

Following Smets and Wouters (2007) the corresponding measurement equation is:

$$Y_t = \begin{pmatrix} dlGDP_t \\ dlCONS_t \\ dlINV_t \\ dlWAG_t \\ dlHOURS_t \\ dlP_t \\ FEDFUNDS_t \\ dlPT_t \end{pmatrix} = \begin{pmatrix} \bar{\gamma} \\ \bar{\gamma} \\ \bar{\gamma} \\ \bar{\gamma} \\ \bar{l} \\ \bar{\pi} \\ \bar{r} \\ \bar{\pi}^T \end{pmatrix} + \begin{pmatrix} y_t - y_{t-1} \\ c_t - c_{t-1} \\ i_t - i_{t-1} \\ w_t - w_{t-1} \\ l_t \\ \pi_t \\ r_t \\ \pi_t^T \end{pmatrix} \tag{26}$$

where l and dl stand for 100 times log and log difference, respectively. Consumption, real GDP, investment and wages share a common trend growth rate, 100(γ - 1). $\bar{\pi} = 100(\Pi_* - 1)$ is the quarterly steady-state inflation rate; and $\bar{r} = 100(\beta^{-1}\gamma^{\sigma_c}\Pi_* - 1)$ is the steady-state nominal interest rate. Given the estimates of the trend growth rate and the steady-state inflation rate, the latter will be determined by the estimated discount rate. $\bar{l}$ is steady-state hours worked, which is normalized to equal zero. The quarterly steady state target inflation rate is calculated by $\bar{\pi}^T = 100(\Pi_*^T - 1)$. Next I discuss the choice of the the prior distribution used in our estimation.

A.6. Forming priors

While most of the priors are selected with a similar approach as Smets and Wouters (2007), we need to motivate how we select the priors for the Taylor rule. Five parameters are fixed in the estimation procedure. The quarterly depreciation rate δ is fixed at 0.025, and the exogenous spending-GDP ratio g_y is set at 18%. Both of these parameters would be difficult to estimate unless the investment and exogenous spending ratios would be directly used in the measurement equation. Three other parameters are clearly not identified: the steady-state mark-up in the labor market (λ_w), which is set at 1.5, and the curvature parameters of the Kimball aggregators in the goods and labor market (ϵ_p and ϵ_w), which are both set at 10. The parameters of the utility function are assumed to be distributed as follows. The intertemporal elasticity of substitution is set at 1.5 with a standard error of 0.375; the habit parameter is assumed to fluctuate around 0.7 with a standard error of 0.1 and the elasticity of labor supply is assumed to be around 2 with a standard error of 0.75. These are all quite standard calibrations. The prior on the adjustment cost parameter for investment is set around 4 with a standard error of 1.5 (based on CEE, 2005) and the capacity utilisation elasticity is set at 0.5 with a standard error of 0.15. The share of fixed costs in the production function is assumed to have a prior mean of 0.25. Finally, there are the parameters describing the price and wage setting. The Calvo probabilities are assumed to be around 0.5 for both prices and wages, suggesting an average length of price and wage contracts of half a year. This is compatible with the findings of Bils and Klenow (2004) for prices. The prior mean of the degree of indexation to past inflation is also set at 0.5 in both goods and labor markets, which is somewhat larger than the findings in the micro econometric studies by Griffin (1996) based on U.S. data.

The priors on the stochastic processes are harmonised as much as possible. The standard errors of the innovations are assumed to follow an inverse-gamma distribution with a mean of 0.10 and two degrees of freedom, which corresponds to a rather loose prior. The persistence of the AR(1) processes is beta distributed with mean 0.5 and standard deviation 0.2. A similar distribution is assumed for the MA parameter in the process for the price and wage mark-up. The quarterly trend growth rate is assumed to be Normal distributed with mean 0.4 (quarterly growth rate) and standard deviation 0.1. The steady-state inflation rate and the discount rate are assumed to follow a gamma distribution with a mean of 2.5% and 1% on an annual basis. The parameters describing the monetary policy rule are based on a different specifications of the Taylor rule, each of which give us a unique mapping of the interest rate, inflation, output gap to the inflation target. The parameters δ_a, δ_b, δ_g, δ_i, δ_w and δ_p are not fully identified, and the priors are set to 0, and we allow the model estimation to give us the complete estimation of these parameters. While previous studies on the subject do not have a time series for the inflation target, we have estimated various possible estimates of the inflation target, and allow the complete model to give us the most likely estimates of these parameters. ρ_π are set to those estimated in the section 2.

Table 13: Feedback rule Robustness, 1959q1 - 2004q3

Parameter	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
ρ_v	0.32	0.23	0.18	0.80	0.42	0.25	0.14	0.20	0.17
σ_v	0.26	0.25	0.25	0.45	0.47	0.26	0.25	0.26	0.25
δ_a	-	0.0053	-	0.0175	-0.0077	-0.013	-0.0031	-	-
δ_g	-	0.0090	-	-0.0138	0.0051	0.0283	0.0063	-	-
δ_b	-	-0.0073	-	-0.0033	-0.0058	-0.0071	0.0076	-	-
δ_i	-	0.0019	-	0.0032	0.0073	-0.0108	0.0042	-	-
δ_w	-	0.0019	-	0.0068	-0.0071	0.0019	-	-0.0190	-
δ_p^p	-	-0.0077	-	-0.0013	-0.0127	-0.0151	-	-0.0045	-
LL(MHME)	-1104.5	-917.9	-921.2	-1128.1	-999.51	-1186.6	-996.28	-940.23	-994.43

The table presents the estimated values of the monetary policy parameters using different specifications of the inflation target. The first panel represents the estimated monetary policy shocks under each specification, while panel 3 reports the marginal density of the model using Geweke (1999) modified harmonic mean estimator.