Monetary Policy, Trend Inflation and the Great Moderation: An Alternative Interpretation

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Abstract: With positive trend inflation, the Taylor principle is not enough to guarantee a determinate equilibrium. We provide new theoretical results on restoring determinacy in New Keynesian models with positive trend inflation and combine these with new empirical findings on the Federal Reserve’s reaction function before and after the Volker disinflation to find that 1) while the Fed satisfied the Taylor principle in the pre-Volker era, the US economy was still subject to self-fulfilling fluctuations in the 1970s, 2) while the Fed’s response to inflation is not statistically different before and after the Volker disinflation, the US economy nonetheless moved from indeterminacy to determinacy in this time period, 3) since the 1970s, the Fed has largely switched from responding to the output gap to responding to output growth, and 4) the change from indeterminacy to determinacy is due to the simultaneous decrease in the response to the output gap, increases in the response to inflation and output growth and the decline in steady-state inflation from the Volker disinflation.

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JEL: C22, E3, E43, E5
I- Introduction

The pronounced decline in macroeconomic volatility since the early 1980s, frequently referred to as the Great Moderation, has been the source of significant debate. One prominent explanation for this phenomenon is that monetary policy became more “hawkish” with the ascent of Paul Volker as Federal Reserve chairman in 1979. Originally proposed by Taylor (1999) and Clarida et al (2000), this view emphasizes that in the late 1960s and 1970s, the Fed systematically failed to respond strongly enough to inflation, thereby leaving the US economy subject to self-fulfilling expectations-driven fluctuations. The policy reversal enacted by Volker and continued by Greenspan, namely the increased focus on fighting inflation, stabilized inflationary expectations and removed this source of economic instability. While this view has received recent support (see Lubik and Schorfheide (2004) and Boivin and Giannoni (2006)), it has also come under challenge in a set of papers by Orphanides (2001, 2002, 2004). The latter argues that once one properly accounts for the central bank’s real-time forecasts, monetary policy-makers in the pre-Volker era responded to inflation in much the same way as those in the Volker and Greenspan periods. Thus, self-fulfilling expectations could not have been the source of instability in the 1970s. Instead, Orphanides emphasizes the stronger response to output gap measures employed by the Fed before Volker, combined with the difficulty of properly measuring the gap in real-time, as the primary source of economic instability of the era preceding the Great Moderation.

Underlying this debate is the Taylor principle: the idea that if the central bank raises interest rates more than one for one with inflation, then self-fulfilling expectations will be eliminated as a potential source of fluctuations. This intuitive concept is commonly used to differentiate between active (“hawkish”) and passive (“doveish”) policy and is a hallmark of modern monetary policy. In addition, it has broad theoretical support from standard New Keynesian models with zero steady-state inflation in which self-fulfilling expectations can occur only when the Taylor principle is not followed, i.e. when monetary policy is passive. Yet recent work by Ascari and Ropele (2007), Kiley (2007) and Hornstein and Wolman (2005) has uncovered an intriguing result: the Taylor principle breaks down when average inflation is positive. Using different theoretical monetary models, these authors all find that achieving a unique Rational Expectations Equilibrium (REE) at historically typical inflation levels requires much stronger responses to inflation than anything observed in empirical estimates of central banks’ reaction functions. In addition, Ascari and Ropele (2007) and Kiley (2007) uncover that having the central bank

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1 Other explanations emphasize inventory management or a change in the volatility of shocks. See Kahn et al (2002) for the former and Blanchard and Simon (2001) or Justiniano and Primiceri (forthcoming) for examples of the latter.

2 See also Bullard and Eusepi (2005) for support for this view.

3 See Woodford (2003).
respond to the output gap – a stabilizing property when steady-state inflation is zero – can be destabilizing under positive steady state inflation rates.

The theoretical breakdown of the Taylor principle in the presence of positive trend inflation calls into question the interpretation of earlier results. For example, finding that the Fed’s inflation response satisfied the Taylor principle after Volker took office – as in Clarida et al (2000) – does not necessarily imply that self-fulfilling expectations could not still occur since the inflation rate averaged around three percent per year rather than the zero percent needed for the Taylor principle to apply. In addition, the argument by Orphanides (2002) that monetary policy-makers satisfied the Taylor principle even before Volker became chairman does not necessarily invalidate the conclusion of Taylor (1999) and Clarida et al (2000) that the US economy moved from indeterminacy to determinacy around the time of the Volker disinflation: the same response to inflation by the central bank can lead to determinacy at low levels of inflation but indeterminacy at higher levels of inflation. Thus, it could be that the Volker disinflation of 1979-1982, by lowering average inflation, was enough to shift the US economy from indeterminacy to the determinacy region even with no change in the response of the central bank to macroeconomic variables.

This paper offers two main contributions. First, we provide new theoretical results on how determinacy can be achieved in New Keynesian models with positive trend inflation. Second, we combine these theoretical results with new empirical findings to provide novel insight into how monetary policy changes may have affected the stability of the US economy over the last forty years. For the former, we build on the work of Ascari and Ropele (2007), Kiley (2007), and Hornstein and Wolman (2005) by uncovering several monetary policy measures which can help ensure the existence of a unique REE. For one, we find that interest smoothing helps reduce the minimum long-run response of interest rates to inflation needed to ensure determinacy. This differs substantially from the zero steady-state inflation case, in which inertia in interest rate decisions has no effect on determinacy prospects conditional on a long-run response of interest rates to inflation.4 We also find that price-level targeting helps achieve determinacy under positive trend inflation, even when the central bank does not force the price level to fully return to its target path. Finally, while Ascari and Ropele (2007) emphasize the potential destabilizing role of responding to the output gap, we show that responding to output growth can help restore determinacy for plausible inflation responses. Thus, a secondary contribution of this paper is to provide new support for Walsh (2003) and Orphanides and Williams (2006), who call for monetary policy makers to respond to output growth rather than the gap.

These results are not just theoretical curiosities since empirical work has found evidence for each of these measures in monetary policy decisions. Interest smoothing is a particularly well-known

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4 Super-inertial rules continue to guarantee determinacy, as with zero steady-state inflation.
empirical feature of interest-rate decision-making. Gorodnichenko and Shapiro (2007) provide evidence for partial price-level targeting in the US. Finally, Ireland (2004) finds that the Fed responds to both the output gap and output growth. Thus, given that these policy actions are empirically and theoretically relevant, one cannot study the determinacy prospects of the economy without considering simultaneously 1) the steady-state rate of inflation, 2) the Fed’s response to inflation and its response to the output gap, output growth, price-level gap, and the degree of interest smoothing, and 3) the economic model.

We revisit the issue of possible changes in monetary policy over the last forty years, as well as the implications for economic stability, using a two-step approach. First, we estimate the Fed’s reaction function before and after the Volker disinflation. We follow Orphanides (2004) and use the Greenbook forecasts prepared by the Federal Reserve staff before each meeting of the Federal Open Market Committee (FOMC) as real-time measures of expected inflation, output growth, and the output gap. We find that while the Fed’s long-run response to inflation is higher in the latter period, the difference is not statistically significant. In addition, the Taylor principle is satisfied in both time periods for most specifications. Thus, in terms of the Fed’s inflation response, our results support the claims of Orphanides and contradict the earlier findings of Clarida et al (2000). On the other hand, we do find that all other aspects of the Taylor rule have changed across the two periods. For one, the persistence of interest rate changes has gone up. Second, like Orphanides (2004), we find that the Fed significantly reduced its response to the output gap. However, we also uncover the novel finding that the Fed has increased its response to output growth. Thus, whereas the common wisdom is that the Fed has reduced its focus on the real economy since the Volker disinflation, our results indicate that the Fed has instead altered the measure of the real economy to which it responds: from the output gap to output growth. All three changes, according to our theoretical results, make determinacy a more likely outcome.

The second step is to feed our empirical estimates of the Taylor rule into a standard New Keynesian model. This allows us to study under what conditions determinacy could have occurred in each time period. We find that given the Fed’s response function in the 1970s and the high average rate of inflation over this time period, 6%, the US economy was indeed in a region of indeterminacy prior to the Volker disinflation. On the other hand, given the Fed’s response function since the early 1980s and the low average rate of inflation over this time period, 3%, we conclude that the US economy has most likely been in a determinate equilibrium since the Volker disinflation. Thus, we concur with the original conclusion of Clarida et al (2000). But whereas these authors reach their conclusion primarily based on the Fed’s changing response to inflation, we argue that the switch from indeterminacy to determinacy was

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6 What we mean by “most likely” is that the estimated parameters of the Taylor rule over this time period yield a determinate REE at 3% inflation and that, if we draw repetitively from the distribution of estimated parameters, over 90% of draws (on average) will yield a determinate REE as well. We discuss this more carefully in section 4.2.
due to several factors, none of which would likely have sufficed on their own. For example, taking the Fed’s pre-Volker response function and replacing any of the individual responses to macroeconomic variables with their post-1982 value would have had no effect on determinacy given the high average inflation rate in the 1970s. Instead, the most important factors causing the switch away from indeterminacy were the higher inflation response combined with the lower output gap response, higher response to output growth and the decrease in steady-state level of inflation. The latter is particularly noteworthy because our baseline results imply that the post-Volker monetary policy rule, while consistent with determinacy at the average 3% inflation rate of the post-1982 period, could lead to indeterminacy at the 1970s’ level of inflation.7 Thus, just as Cogley and Sbordone (2008) find that controlling for trend inflation has important implications in the estimation of the New Keynesian Phillips Curve, we conclude that trend inflation also plays a critical role in better understanding the ability of monetary policy-makers to stabilize the economy. Devoting more effort to understanding the determinants of trend inflation, as in Sargent (1999), Primiceri (2008) or Ireland (forthcoming), and the Volker disinflation of 1979-1982 in particular, is likely to be a fruitful area for future research.

While we reach the same conclusion about indeterminacy in the pre-Volker era as Clarida et al (2000), our finding that the Fed’s response to the output gap plays an important role in reaching that conclusion echoes closely the arguments of Orphanides (2004). But whereas Orphanides emphasized the potentially destabilizing property of responding to an output gap that is imprecisely measured in real-time, we focus on the fact that responding to the output gap can be destabilizing in the determinacy sense. Note that the two explanations are not mutually exclusive. In fact, one could integrate mismeasurement of the output gap by the central bank into our model and thereby directly assess the relative importance of the two mechanisms in accounting for the decreased volatility of the post-Volker era. In addition, whereas Orphanides characterizes the post-1982 era as less focused on stabilizing output because of a diminished response to the output gap, we conclude instead that this lower response to the gap has been compensated by a much stronger response to output growth.

Our finding that Fed policy between 1983 and 2002 could be inconsistent with determinacy at 1970s-level inflation rates begs the question of how policy-makers could alter this situation. Here, we find that the complete elimination of the Fed’s current response to the output gap would remove virtually any chance of indeterminacy, even at 1970s levels of inflation. But this does not imply that central banks should, in general, not respond to the real side of the economy. The last result holds only because, since Volker, the Fed has been responding strongly to output growth. Were the Fed to stop responding to both

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7 Note that Cogley et al (2008) similarly argue that much of the decrease in volatility can be explained by a combination of the change in the parameters of the Fed’s reaction function and changes in the behavior of the Fed’s target inflation. However, their argument is based on estimation of a DSGE model that does not allow for indeterminacy and is thus qualitatively different from our interpretation of the data.
the output gap and output growth, indeterminacy at higher inflation rates would become an even more likely outcome.

Our approach is also very closely related to Lubik and Schorfheide (2004) and Boivin and Giannoni (2006). Both papers address the same question of whether the US economy has switched from indeterminacy to determinacy because of monetary policy changes, and both reach the same conclusion as us. However, our approaches are quite different. First, we emphasize the importance of allowing for positive steady-state inflation, whereas their models are based on zero-inflation approximations. Thus, their models ignore the determinacy implications of positive steady-state inflation and cannot take into account the effects on determinacy of the lower steady-state inflation brought about by the Volker disinflation. Second, we consider a larger set of policy responses for the central bank, which we argue has significant implications for determinacy as well. Third, we estimate the parameters of the Taylor rule using real-time Fed forecasts, whereas these papers impose rational expectations on the central bank in their estimation. Finally, we draw our conclusions about determinacy by feeding our empirical estimates of the Taylor rule into a pre-specified model, whereas they estimate the structural parameters of the DSGE model jointly with the Taylor rule. The pros and cons of the latter are well-known: greater efficiency in estimation as long as the model is specified correctly. However, if any part of the model is mis-specified, this can affect all of the other estimated parameters. Our approach instead allows us to estimate the parameters of the Taylor rule using real-time data while imposing as few restrictions as possible. We are then free to consider the implications of these parameters in any model we like. While much more flexible than estimating a DSGE model, our approach does have two key limitations. First, we are forced to select parameter values for the model, rather than estimating them. Second, because we do not estimate the shock processes, we cannot quantify the effect of our results as completely as in a fully specified and estimated DSGE model.

The paper is structured as follows. Section 2 presents the model, while section 3 presents new theoretical results on determinacy under positive trend inflation. Section 4 presents our Taylor rule

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8 In the case of Lubik and Schorfheide (2004), they use the standard NKPC expressed in terms of deviations from a non-zero steady state rate of inflation. This is equivalent to using a Calvo pricing model in which non-reoptimized prices are fully indexed to steady-state inflation. This eliminates all of the determinacy implications of positive trend inflation, as described in section 4.4.

9 For example, neither Lubik and Schorfheide (2004) nor Boivin and Giannoni allow for a response to output growth in the Taylor rule.

10 Estimation of DSGE models under indeterminacy also raises additional issues such as selecting one of many equilibrium outcomes.

11 For example, while our baseline model relies on Calvo (1983) price setting, we can just as easily apply our Taylor rule estimates to a model with staggered price setting (as in Taylor (1977)), which we do in section 4.4. This is not the case using an estimated DSGE model, knowing that the estimated Taylor rule coefficients are sensitive to the price-setting assumptions of the model.
estimates and their implications for US determinacy since the 1970s, as well as robustness exercises. Section 5 concludes.

II- Model

We rely on a standard New Keynesian model, in which we focus on allowing for positive trend inflation.

2.1 The Model

The representative consumer maximizes expected utility over consumption \( C \) and labor \( N \),

\[
max E_t \left( \sum_{j=0}^{\infty} \beta^j \left[ \ln C_{t+j} - (1 + \eta^{-1})^{-1} \int_0^1 N(t)^{1+\eta^{-1}} \, dt \right] \right)
\]

Note that labor is provided individually to a continuum of industries. The budget constraint at time \( t+j \) is given by

\[
C_{t+j} + \frac{B_{t+j}}{P_{t+j}} \leq \int_0^1 N(i)_{t+j} W(i)_{t+j} \, di + \frac{B_{t+j-1} R_{t+j-1}}{P_{t+j}} + T_{t+j}
\]

where \( B \) is the stock of bonds held, \( W(i) \) is the nominal wage paid by sector \( i \), \( P \) is the price index of the consumption good, \( R \) is the nominal interest rate, and \( T \) is a lump-sum transfer from ownership of firms. The FOC’s for the consumer are given by

\[
C_t N_t^{\eta^{-1}} = \frac{W(i)_t}{P_t}
\]

\[
1 = \beta E_t \left[ \frac{C_t}{C_{t+1}} R_t \frac{P_t}{P_{t-1}} \right]
\]

As we abstract away from investment, international trade, and government consumption, aggregate consumption must equal the production of the final good \( Y \), which is an aggregate of intermediate goods produced by a continuum of firms indexed by \( i \) based on the CES aggregator

\[
C_t = Y_t = \left[ \int_0^1 Y(i)_t \frac{1}{\theta} \, di \right]^{\frac{\theta}{\theta-1}}
\]

where \( \theta \) is the elasticity of substitution across intermediate goods. Profit-maximization by perfectly-competitive final goods producers yields the demand curve for each intermediate good \( i \)

\[
Y(i)_t = Y_t \left( \frac{P(i)_t}{P_t} \right)^{-\theta}
\]

and the aggregate price index

\[
P_t = \left[ \int_0^1 P(i)_t^{1-\theta} \, di \right]^{(1-\theta)^{-1}}
\]
Intermediate goods are produced by a continuum of monopolistic competitors with a production function with only labor as an input and constant returns to scale

\[ Y(i)_t = A_t N(i)_t \]

where \( A \) is the aggregate productivity level. The log of productivity is assumed to follow a random walk with drift process

\[ \ln A_t = g + \ln A_{t-1} + \varepsilon_t^A. \]

Following Calvo (1983), we assume that each period, firms face a constant probability \( 1 - \theta_{sp} \) of not being to change their price. Defining \( B_t(i) \) to be the reset price of a firm \( i \) when it has the opportunity to change its price, the firm chooses its reset price to maximize the expected present discounted utility stream of future profits

\[ \max E_t \sum_{j=0}^{\infty} \theta_{sp}^j Q_{t,t+j} Y(i)_{t+j} [B_t(i) - MC(i)_{t+j}]. \]

Substituting the firm’s demand curve into the expression and maximizing with respect to \( B_t(i) \) yields the first-order condition

\[ \frac{B_t(i)}{P_t} = \frac{\theta}{\theta - 1} E_t \frac{\sum_{j=0}^{\infty} \theta_{sp}^j Q_{t,t+j} Y_t Y_{t+j} \left( \frac{P_{t+j}}{P_t} \right)^{\theta+1} \left( \frac{MC(i)_{t+j}}{P_{t+j}} \right)}{\sum_{j=0}^{\infty} \theta_{sp}^j Q_{t,t+j} Y_{t+j} \left( \frac{P_{t+j}}{P_t} \right)^{\theta}}. \]

Noting that \( MC(i)_t = \frac{W(i)_t}{A_t} \left( \frac{y_t}{A_t} \right)^{1+\eta} \left( \frac{P_t}{P_t} \right)^{\frac{\theta}{\eta}} \left( \frac{P_{t+j}}{P_t} \right)^{\frac{\theta}{\eta}} \) and substituting in this expression for firm-specific marginal cost into the reset price equation yields

\[ \left( \frac{B_t}{P_t} \right)^{1+\theta/\eta} = \frac{\theta}{\theta - 1} E_t \frac{\sum_{j=0}^{\infty} \theta_{sp}^j Q_{t,t+j} Y_t Y_{t+j} \left( \frac{P_{t+j}}{P_t} \right)^{1+\theta(1+\eta^{-1})} \left( \frac{Y_{t+j}}{A_{t+j}} \right)^{1+\eta^{-1}}}{\sum_{j=0}^{\infty} \theta_{sp}^j Q_{t,t+j} Y_{t+j} \left( \frac{P_{t+j}}{P_t} \right)^{\theta}}. \]

where we’ve dropped individual firm subscripts since all firms which can reset their price at time \( t \) will choose the same price. Finally, we want to express the reset price equation as a function of stationary variables. To do so, first note that the flexible price level of output is given by

\[ Y^f_t = \left( \frac{\theta - 1}{\theta} \right)^{(1+\eta^{-1})^{-1}} A_t. \]

The output gap can then be defined as \( X_t \equiv Y_t/Y^f_t \). Also, note that the stochastic discount factor is given by

\[ Q_{t,t+j} = \frac{\beta^j Y_t P_t}{Y_{t+j} P_{t+j}} = \prod_{i=1}^{j} R_{t+i-1}. \]
Finally, defining $GY_t \equiv Y_t / Y_{t-1}$ as the growth rate of output and $Π_t \equiv P_t / P_{t-1}$ as the inflation rate, we can rewrite the expression for the relative reset price in terms of stationary variables

$$
\left( \frac{B_t}{P_t} \right)^{1+\theta/\eta} = E_t \frac{\sum_{j=0}^{\infty} \theta_{sp}^j \left[ \prod_{i=1}^{j} GY_t^{1+\eta^{-1}} \right] X_t^{1+\eta^{-1}}}{\sum_{j=0}^{\infty} \theta_{sp}^j \left[ \prod_{i=1}^{j} GY_t^{1+\eta^{-1}} \right] X_t^{1+\eta^{-1}}}
$$

(1)

The price level can be decomposed into a function of the current reset price and an autoregressive component

$$
P_t^{1-\theta} = (1 - \theta_{sp})B_t^{1-\theta} + \theta_{sp}P_t^{1-\theta}.
$$

Normalizing both sides by the current price level and rearranging yields an alternative representation in terms of stationary variables

$$
1 = (1 - \theta_{sp}) \left( \frac{B_t}{P_t} \right)^{1-\theta} + \theta_{sp} P_t^{\theta-1}.
$$

2.2 Log-Linearization

Following most of the literature, we focus on a first-order approximation to the model but depart from the standard approach in allowing for the steady-state level of inflation ($\bar{Π} - 1$) to be greater than or equal to zero. This has no effect on the first-order conditions of the consumer’s problem. Thus, letting lower-case letters denoted the log-deviation of a variable from its steady-state value, we can write the dynamic IS equation as

$$
E_t g y_{t+1} = γ_t - E_t π_{t+1}
$$

and the link between output growth and the change in the output gap as

$$
g y_t = x_t - x_{t-1} + η_t^α.
$$

However, non-zero trend inflation has important effects on the linearization of the price-setting equations. First, positive trend inflation ($\bar{Π} > 1$) implies that reset prices will, on average, be higher than the average price level

$$
\bar{b} = \left( \frac{1 - \theta_{sp} \bar{Π}^{\theta-1}}{1 - \theta_{sp}} \right)^{(1-\theta)^{-1}}
$$

as long as the elasticity of substitution is greater than 1. This reflects the fact that a fixed reset price will erode in real terms because of inflation. This implies that (log-linearized) inflation becomes less sensitive to changes in the (log-linearized) relative reset price

$$
π_t = \left( \frac{1 - \theta_{sp} \bar{Π}^{\theta-1}}{\theta_{sp} \bar{Π}^{\theta-1}} \right) b_t.
$$

because, on average, firms who change prices set them above the average price level and therefore account for a smaller share of expenditures than others.
More importantly for determinacy issues, the reset price equation is also sensitive to trend inflation. The log-linearized version of equation (1) is

\[(1 + \theta \eta^{-1}) b_t = (1 + \eta^{-1})(1 - \gamma_2) \sum_{j=0}^{\infty} \gamma_j^j E_t x_{t+j} + E_t \sum_{j=1}^{\infty} (\gamma_j^j - \gamma_1^j)(\gamma y_{t+j} - r_{t+j-1}) + \sum_{j=1}^{\infty} [\gamma_j^j (1 + \theta (1 + \eta^{-1})) - \gamma_1^j \theta] E_t \pi_{t+j} \]

where \(\gamma_1 \equiv \theta \pi^{R-1} \gamma \gamma^{\pi \theta}\) and \(\gamma_2 \equiv \gamma_1 \pi^{1 + \theta \eta^{-1}}.\)

Consider how positive trend inflation affects the relative reset price. First, higher steady-state inflation raises \(\gamma_2\), so that the weights in the output gap term shift away from the current gap and more towards future output gaps. This reflects the fact that as the relative reset price falls over time, the firm’s future losses will tend to grow very rapidly. Thus, a sticky-price firm must be relatively more concerned with marginal costs far in the future when trend inflation is positive. Second, the relative reset price now depends on the discounted sum of future differences between output growth and interest rates. Note that this term disappears when steady-state inflation is zero. This factor captures the scale effect of aggregate demand in the future. The higher aggregate demand is expected to be in the future, the bigger the firm’s losses will be from having a deflated price. The interest rate captures the discounting of future gains. When steady-state inflation is zero, these two factors cancel out on average. Positive trend inflation, however, induces the potential for much bigger losses in the future which makes these effects first-order. Thus, as with the output gap, positive trend inflation induces more forward-looking behavior on the part of firms. Third, positive trend inflation raises the coefficient on expected inflation. This reflects the fact that the higher is expected inflation, the more rapidly the firm’s price will depreciate, the higher it must set its reset price. Thus, positive trend inflation makes firms more forward-looking in their price-setting decisions by raising the importance of future marginal costs and inflation, as well as by inducing them to also pay attention to future output growth and interest rates.

The log-linearized reset price equation can also be rewritten in a more convenient form as

\[b_t = (1 + \theta \eta^{-1})^{-1} (d_t - e_t)\]

where the variables \(d_t\) and \(e_t\) follow respectively

\[d_t = (1 - \gamma_2)(1 + \eta^{-1}) x_t + \gamma_2 E_t [\gamma y_{t+1} - r_t + (1 + \theta (1 + \eta^{-1})) \pi_{t+1}] + \gamma_2 E_t d_{t+1}\]

\[e_t = \gamma_1 E_t [\gamma y_{t+1} - r_t + \theta \pi_{t+1}] + \gamma_1 E_t e_{t+1}.\]

\(^{12}\) Note that for the reset price to have a well-defined solution in the steady-state requires that \(\gamma_2 < 1\gamma\). See Bakhshi et al (2007).
2.3 Calibration

Allowing for positive trend inflation increases the state space of the model and makes analytical solutions infeasible. Thus, all of our determinacy results are numerical. We calibrate the model as follows. The Frisch labor supply elasticity, $\eta$, is set to 1. We let $\beta=0.99$ and the steady-state growth rate of real GDP per capita be 1.5% per year ($GY = 1.015^{0.25}$), which matches the U.S. rate from 1969 to 2002. The elasticity of substitution $\theta$ is set to 10. Finally, the degree of price stickiness ($\theta_{sp}$) is set to 0.55, which amounts to firms resetting prices approximately every 7 months on average. This is midway between the micro estimates of Bils and Klenow (2004), who find that firms change prices every 4 to 5 months, and those of Nakamura and Steinson (forthcoming), who find that firms change prices every 9 to 11 months. We will investigate the robustness to this key parameter in subsequent sections.

III- Equilibrium Determinacy under Positive Trend Inflation

To close the model, we need to specify how monetary policy-makers set interest rates. One common description is a simple Taylor rule:

$$r_t = \phi_r E_t \pi_{t+j}$$  \hspace{1cm} (2)

in which the central bank sets interest rates as a function of contemporaneous ($j=0$) or future ($j>0$) inflation. As documented in Woodford (2003), such a rule, when applied to a model like the one presented here with zero steady-state inflation, yields a simple and intuitive condition for the existence of a unique rational expectations equilibrium: $\phi_r > 1$.\(^{13}\) This result, which we will refer to as the Basic Taylor Principle, states that central banks must raise interest rates by more than one-for-one to eliminate the possibility of sunspot fluctuations.

Yet, as emphasized in Ascari and Ropele (2007), Kiley (2007), and Hornstein and Wolman (2005), the basic Taylor principle loses its potency in environments with positive trend inflation. To illustrate this in our model, we first need to assign parameter values. Figure 1 presents the minimum response of the central bank to inflation necessary to ensure the existence of a unique rational expectations equilibrium for both contemporaneous ($j=0$) and forward-looking ($j=1$) Taylor rules.\(^{14}\) As found by Ascari and Ropele (2007), Kiley (2007), and Hornstein and Wolman (2005), as the steady-state inflation rate rises, the basic Taylor principle breaks down. With a contemporaneous Taylor rule, after inflation exceeds 1.5 percent per year, the minimum response needed by the central bank starts to rise.

\(^{13}\) Forward-looking rules, $j \geq 1$, typically also place a constraint on the maximum value of $\phi_r$ to sustain a unique REE. See Woodford (2003, chapter 4).

\(^{14}\) For simplicity, we focus on the minimum response of inflation necessary for a unique REE, and do not plot the maximum values typical in forward-looking responses. This is because these, when present, are always at levels far beyond anything seen in empirical estimates of Taylor rules.
With steady-state inflation of 6 percent a year, as was the case in the 1970s, the central bank would have to raise interest rates by more than five times the increase in the inflation rate to sustain a determinate REE. Using forward-looking Taylor rules, the results are even more dramatic. As soon as inflation slightly exceeds 0 percent per year, the minimum response to inflation exceeds our maximum bound of 20, implying that a determinate REE does not exist for plausible inflation responses even at very low inflation rates. This breakdown of the basic Taylor principle reflects the growing importance of forward-looking behavior in price-setting when steady-state inflation rises. Note that this result is not limited to Calvo pricing. Kiley (2007) and Hornstein and Wolman (2005) find similar results using staggered contracts a la Taylor (1977).\(^{15}\)

In the rest of this section, we investigate modifications of the basic Taylor rule and study how these affect the prospects for a determinate equilibrium under positive trend inflation. In particular, we focus on two types of responses to the real side economy: the output gap and output growth, as well as two sources of inertia in interest rate decisions, interest rate smoothing and price level targeting.

3.1 Responding to the Output Gap

One variation on the basic Taylor rule which has received much attention in the literature is allowing for the central bank to respond to the output gap. Thus, one would write the Taylor rule as

\[
r_t = \phi\pi_t + \phi_x x_{t+j}
\]

This reflects the fact that empirical estimates of Taylor rules typically find a positive response of interest rates to the real side of the economy as well as the fact that responding to the output gap can be stabilizing in theory. For example, Woodford (2003) shows that in a model similar to the one presented above with zero steady-state inflation, a contemporaneous \((j=0)\) Taylor rule will ensure a determinate REE if

\[
\phi_{\pi} + \frac{(1 - \beta)}{\kappa}\phi_{x} > 1
\]

which is commonly known as the Generalized Taylor Principle.\(^{16}\) This result follows from the fact that in the steady-state, there is a positive relationship between inflation and the output gap. Thus, a permanent one percent increase in inflation leads to a long-run increase in the output gap (of \((1 - \beta)/\kappa\) percent so that the left-hand side of the Generalized Taylor Principle corresponds to the long-run increase in the interest rate from a permanent one-percent increase in inflation. If this is greater than one, then determinacy is ensured. The Generalized Taylor Principle implies that determinacy can be achieved by a sufficiently strong response to the output gap, a sufficiently strong response to inflation, or

\(^{15}\) Appendix Figure 1 reproduces the baseline determinacy issue with staggered price setting (under the assumption that prices are set for 3 quarters), yielding qualitatively similar results.

\(^{16}\) In our model, \(\kappa \equiv (1 - \theta_{sp})(1 - \beta\theta_{sp})/[\theta_{sp}(1 + \theta^{-1})].\)
some combination thereof. In any case, responding to the output gap is clearly positive in terms of ensuring determinacy.

Yet as demonstrated by Ascari and Ropele (2007) and Kiley (2007), this extension of the Taylor principle breaks down as well with positive trend inflation because the slope of the NKPC turns negative for high enough steady-state level of inflation. Figure 2 presents the minimum response to inflation necessary to achieve determinacy for different trend levels of inflation and different responses to the output gap. The results are nonlinear. Small but positive responses to the output gap lead to lower minimum responses to inflation achieve determinacy, as was the case with zero steady-state inflation. However, stronger responses to the output gap (generally greater than 0.5) have the opposite effect and require bigger responses to inflation to sustain a unique REE. This result has important policy implications which clash with those implied by the Generalized Taylor Principle. With positive trend inflation, strong responses to the output gap can be destabilizing rather than stabilizing.

3.2 Responding to Output Growth
The results for responding to the output gap under positive trend inflation call into question whether central banks should be responding to the real side of the economy at all, even when one ignores the uncertainty regarding real-time measurement of the output gap. Yet recent work by Orphanides and Williams (2006) and Walsh (2003) has emphasized an alternative real variable that monetary policy makers can respond to for stabilization purposes: output growth. This policy, sometimes referred to as “speed limit”, has the advantage of greatly reducing measurement issues since output growth is directly observable. To determine how such a policy might affect determinacy with trend inflation, we consider the following Taylor rule

\[ r_t = \phi_p E_t \pi_{t+1} + \phi_y E_t g y_{t+1} \]  (4)

Figure 3 presents the minimum response to inflation needed by the central bank to ensure determinacy for different trend inflation rates and responses to output growth. For both contemporaneous and forward-looking Taylor rules, having the central bank respond to output growth helps ensure determinacy of the equilibrium. The minimum level of inflation response needed for determinacy falls as the response to output growth increases. In fact, a more general principle appears to be at work here: determinacy appears to be guaranteed for any positive and sustainable inflation rate when the Fed responds to inflation and output growth by more than one-for-one. The stabilizing property of responding to output growth with positive trend inflation comes from the reset price equation. With positive trend inflation, firms take into account the difference between GDP growth and interest rates.

17 In Appendix Figure 2, we present analogous results using staggered contracts, yielding similar results.
18 Appendix Figure 3 presents the same results using staggered price setting.
When interest rates rise with output growth, this decreases the incentive to raise the reset price and therefore helps stabilize inflation expectations.

This result implies that targeting real variables is not automatically destabilizing under positive trend inflation. Instead, strong responses to output growth help restore the basic Taylor principle whereas strong responses to the output gap can be destabilizing. In addition, because output growth is readily observable and subject to much less measurement error than the output gap, having the central bank follow a “speed limit” policy of the type proposed by Walsh (2003) and Orphanides and Williams (2006) appears to be both feasible in real time and helpful in diminishing the possibility of sunspot fluctuations.\(^{19}\)

3.3 Interest Rate Smoothing

An additional extension to the basic Taylor rule which has become exceedingly common is allowing for interest smoothing. One would thus rewrite the basic Taylor rule as

\[
r_t = \rho r_{t-1} + (1 - \rho)\phi_\pi E_t \pi_{t+j}
\]

where \(\rho\) is the degree of interest smoothing. In this case, \(\phi_\pi\) can be interpreted as the long-run response of interest rates to a one-percentage point increase in inflation. As shown in Woodford (2003), such rules are also consistent with the Taylor principle, requiring that the long-run response to inflation \([\phi_\pi]\) be greater than one for any degree of interest smoothing between 0 and 1. In such settings, interest smoothing has no effect on determinacy of the equilibrium, conditional on the long-run response of interest rates to inflation. On the other hand, super-inertial rules (in which \(\rho \geq 1\)) guarantee determinacy for any positive response to inflation, since these imply an infinite long-run response of interest rates to permanent changes in inflation.

We investigate the effect of introducing interest smoothing in the Taylor rule under positive trend inflation in Figure 4.\(^{20}\) For both contemporaneous and forward-looking Taylor rules, higher interest smoothing makes determinacy sustainable at lower levels of \(\phi_\pi\).\(^{21}\) With interest smoothing on the order of 0.9, a value frequently found in empirical work, the Taylor principle is restored for inflation rates as high as 6 percent. This differs from the zero trend inflation case in which only the long-run response to inflation mattered for determinacy. With positive trend inflation, interest smoothing actually helps ensure a determinate REE by restoring the Taylor principle. In addition, super-inertial rules (in which \(\rho \geq 1\))

\(^{19}\) Note also that Schmitt-Grohe and Uribe (forthcoming) find that responding to output growth leads to about the same welfare as policies focused on the gap, conditional on the existence of a unique REE.

\(^{20}\) Appendix Figure 4 presents the same results using staggered price setting. Note that for \(\rho = 1\), we rewrite the Taylor rule as \(r_t = \rho r_{t-1} + \phi_\pi E_t \pi_{t+j}\).

\(^{21}\) Sveen and Weinke (2005) find a similar result but in the context of a New Keynesian model with firm-specific capital and zero steady-state inflation.
continue to guarantee determinacy for any positive response to the inflation rate, exactly as was the case with zero steady-state inflation.

3.4 Price Level Targeting
Another policy approach often considered is price-level targeting (PLT). To model this, we follow Gorodnichenko and Shapiro (2007) and write the Taylor rule as

\[ r_t = \phi_p dp_t \]

where \( dp_t \) is the log deviation of the price level \( (P_t) \) from its target path \( (P_t^*) \)

\[ dp_t \equiv \ln P_t - \ln P_t^* = \delta dp_{t-1} + \pi_t. \]

The price gap depends on the lagged price gap and the current deviation of inflation from the target. The parameter \( \delta \) indicates how “strict” price-level targeting is. In the case of \( \delta = 0 \), the price-level gap is just the deviation of inflation from its target and the Taylor rule collapses to the basic inflation targeting case. When \( \delta = 1 \), we have strict price level targeting in which the central bank acts to return the price level completely back to the target level after a shock. The case of \( 0 < \delta < 1 \) is “partial” price level targeting, in which the central bank forces the price level to return only partway to the original target path.\(^{22}\)

By quasi-differencing the Taylor rule after substituting in the price gap process, one can readily show that this policy is equivalent to the following Taylor rule:

\[ r_t = \delta r_{t-1} + \phi_p \pi_t \]

This is observationally equivalent to the Taylor rule with interest smoothing. Thus, when the central bank pursues strict PLT \( (\delta = 1) \), this is equivalent to the central bank having a super-inertial rule. Determinacy is therefore guaranteed for any positive response to the price level (and therefore inflation). Thus, the result of Giannoni (2000) that strict PLT guarantees determinacy in a Calvo type model with zero steady state inflation continues to hold (at least numerically) under positive trend inflation. In addition, partial PLT \( (0 < \delta < 1) \) will yield the exact same results as interest smoothing. The stricter the PLT (the higher the \( \delta \)), the smaller the long-run response to inflation will need be to sustain a determinate REE for positive trend levels of inflation.

3.5 Summary
The fact that the basic Taylor principle breaks down with positive trend inflation raises important questions about monetary policy. First, are there other policy actions that can help ensure determinacy? Previous work has shown that responding to the output gap can actually further destabilize the economy when the inflation rate is positive, eliminating one potential source of stability frequently utilized in

\(^{22}\) This could also be interpreted as targeting an average level of inflation. Suppose that the target for average inflation is 2% over 5 years. Then below-target inflation is later compensated with above target inflation.
theoretical and empirical work. What we’ve shown is that three alternative policies can help restore the Taylor principle. Responding to output growth, rather than the output gap, is one way that policy-makers can respond to the real side of the economy in a stabilizing manner. Interest rate inertia and price level targeting are also useful sources of persistence in interest rate decisions which can help achieve determinacy for an economy with trend inflation. Second, whether an economy is subject to sunspot equilibria depends not just on the central bank’s response function but also on the steady-state level of inflation. Thus, a policy rule which is stabilizing for one level of inflation may not be sufficient for determinacy at a higher level of inflation. In other words, changes in the central bank’s inflation target can move an economy from determinacy to indeterminacy even with no change in the central bank’s response to macroeconomic variables. Third, determinacy will tend to be model specific, and thus sensitive to both the structure and parameters of the model. This implies that exercises such as those by Clarida et al (2000) in which one estimates only the parameters of the Taylor rule will in general be incapable of answering the question of whether this rule is consistent with a determinate equilibrium.

IV- Monetary Policy and Determinacy since the 1970s

In this section, we revisit the issue of how monetary policy may have changed before and after the Volker disinflation and how such changes may have moved the economy out of an indeterminate equilibrium in the pre-Volker era. This possibility was first raised by Taylor (1999) and Clarida et al (2000). These authors pointed out that in their estimates of the Taylor rule, the pre-Volker era was characterized by responses to inflation inconsistent with the Taylor principle but that this was not the case after the Volker disinflation. On the other hand, Orphanides (2002) notes that using real time data to estimate the parameters of the Taylor rule eliminates this result: once one properly controls for the central bank’s real time forecasts, the Taylor principle appears to be satisfied each period. Orphanides concludes that the volatility of the 1970s was not due to indeterminacy but rather to a combination of real-time mismeasurement of the output gap and a large response coefficient to the output gap.

Given how determinacy results hinge on the steady-state rate of inflation, we revisit the debate and take into account trend inflation. In section 4.1, we first re-consider estimates of the Taylor rule over each time period. We feed the estimated parameters into our model to assess the implications for determinacy of the differences in response coefficients across the two periods given different steady state inflation rates. In section 4.2, we perform counterfactual experiments to study which changes in the Taylor rule have been most important and what further changes the Federal Reserve could pursue to strengthen the prospects of achieving determinacy. In section 4.3, we investigate the robustness of the
determinacy results to various price setting assumptions, the presence of habit formation, and alternative measurements of the output gap.

An alternative approach would be to estimate the parameters of the Taylor rule jointly with the structural parameters of the rest of the model using full-information or Bayesian methods. This is the approach used by Lubik and Schorfheide (2004) and Boivin and Giannoni (2006).\(^{23}\) We chose not use this approach for several reasons. First, our interest rate data and Greenbook forecasts are for each FOMC meeting, making the time frequency of the interest rate rule inconsistent with that of other observable macroeconomic variables and rendering simultaneous estimation particularly problematic. Second, our estimates of the Fed’s reaction function are conditional on its historical forecasts, without requiring us to model how those forecasts are formed. A full-information estimation approach, on the other hand, would require us to take a stand on the specific expectations formation process used by the central bank. Third, while full-information approaches are commonly applied to determinate equilibria, estimation under indeterminacy requires selecting one out of many potential equilibrium outcomes. While various criteria can be used for this selection, how best to proceed in this case remains a point of contention. Nonetheless, the fact that our results point so strongly to indeterminacy in the pre-Volker era provides support for recent work studying the estimation of DSGE models under indeterminacy. Integrating positive trend inflation and monetary policy rules of the type considered in this paper, along with (potentially) limited information on the part of the central bank, into a DSGE model that can be estimated under determinacy and indeterminacy, while obviously outside the scope of this paper, would be useful in quantifying the relative importance of the elimination of indeterminacy in accounting for the Great Moderation.

4.1 Determinacy before and after the Volker Disinflation

As shown in section 3, determinacy in a model hinges on the steady state of inflation, the structure and parameters of the model, and how the central bank responds to various macroeconomic variables. We first focus on how the Fed’s reaction function may have changed before and after the Volker disinflation. Our estimated Taylor rule is

$$r_t = (1 - \rho_1 - \rho_2) (\phi_\pi E_t \pi_{t+1} + \phi_{gy} E_t g_{y,t+1} + \phi_x E_t x_{t+1}) + \rho_1 r_{t-1} + \rho_2 r_{t-2} + \epsilon_t$$

(6)

This specification allows for interest smoothing of order two, as well as a response to inflation, output growth, and the output gap. Allowing for responses to both the output gap and output growth is necessary because the two have different implications for determinacy with positive trend inflation. To estimate equation (6), we follow Orphanides (2004) and use real-time data for the estimation. Specifically, we use the Greenbook forecasts of current and future macroeconomic variables prepared by staff members of the

\(^{23}\) Note that neither paper explicitly takes into account positive trend inflation.
Fed a few days before each meeting of the Federal Open Market Committee (FOMC). The interest rate is the target federal funds rate set at each meeting, from Romer and Romer (2004). Unfortunately, the Greenbook does not provide measures of the output gap. We create real-time measures of the output gap for each meeting by running the real-time measure of (log) real GDP on a constant and linear time trend with break, and define the lagged output gap as the (log) deviation of output from trend in the final period. We create forecasts of the current and future output gap by using the Greenbook forecasts of GDP growth minus the growth rate of potential output implied by the estimated time trend.

Note that using Greenbook forecasts allows for estimation of the Taylor rule by NLS and therefore avoids the instrument selection and validity issues emphasized by Sims and Zha (2006). In addition, this approach does not require the imposition of a rational expectations assumption of the forecasts of the central bank. Data is available from 1969 to 2002 for each official meeting of the FOMC. We consider two time samples: 1969-1978 and 1983-2002. Thus, we drop the period from 1979-1982 in which the Federal Reserve officially abandoned interest rate targeting in favor of targeting monetary aggregates. Each \( t \) is a meeting of the FOMC. From 1969-1978, meetings were monthly, whereas from 1983 on, meetings were held every 6 weeks. Note that this implies that the interest smoothing parameters in the Taylor rule are not directly comparable across the two time periods.

Table 1 presents results of the estimation of equation (6) over each time period for three cases: contemporaneous Taylor rule \( (j=0) \), forward-looking Taylor rule, and mixed. In the case of the contemporaneous Taylor rule, we use the central bank’s forecast of values for the current quarter. In the case of the forward-looking rule, we use the average forecast over the next two quarters. The mixed case attempts to choose the specification that best fits the data. Specifically, we consider all possible variants of forward-looking and contemporaneous-looking for inflation, output gap, and output growth responses and use the AIC to select the best specification. We find that, in each subsample, interest rate decisions are best modeled as a function of forecasts of future inflation and output gap but current output growth. We will treat this as the baseline in subsequent sections.

The top panel of Table 1 contains the point estimates of each Taylor rule as well as standard errors. In addition, we report the sum of the interest smoothing parameters converted to a quarterly frequency. We also include the probability value of the null that each of the parameters and the sum of

\[ \text{We follow Orphanides and van Nordern (2002) and allow for a break in the trend in 1973, but include this break in the estimation only starting in 1977.} \]

\[ \text{Because there is no convenient formula for converting AR(2) parameters from monthly or 6-weekly frequency to quarterly, we use the following approach. Given estimated AR(2) parameters, we simulate an AR(2) process at the original frequency, and then create a new (average) series at the quarterly frequency. We then regress the quarterly series on two lags of itself over a sample of 50,000 periods and report the sum of the estimated parameters.} \]
interest smoothing parameters are the same in the two periods.\textsuperscript{26} We find that the Fed’s response to inflation in the pre-Volker era satisfied the Taylor principle in forward-looking specifications, but not contemporaneous Taylor rules. Because the forward-looking specification is statistically preferred to a contemporaneous response to inflation, our evidence supports the arguments of Orphanides (2004) that the Fed satisfied the Taylor principle in both periods. Like Orphanides, we also find that while our estimates point to a stronger response by the Fed to inflation in the latter period, we cannot reject the null that there has been no change in the response to inflation. Thus, our estimates of the Fed’s response coefficients do not provide strong support for the claims of Taylor (1999) and Clarida et al (2000) that the failure to satisfy the basic Taylor principle before Volker placed the US economy in an indeterminate region. However, we do find that all other response coefficients have changed in statistically significant ways. First, interest rate decisions have become more persistent, in the sense that the sum of the autoregressive components is higher in the latter period than in the early period, and statistically significantly so in two out of three specifications. Second, the Federal Reserve has changed how it responds to the real side of the economy. Whereas the period before the Volker disinflation was characterized by a strong long-run response to the output gap, but no apparent response to output growth, the period since the Volker disinflation displays much stronger long-run responses by the Fed to output growth than to the output gap.

These results illustrate an important feature of the data: monetary policy has changed across time, despite the fact that one cannot reject the null that the Fed’s response to inflation alone has not changed. Thus were one to rely only on the basic Taylor principle as guidance for establishing determinacy, then one would reach the same conclusion as Orphanides (2004). Yet the results of section 3 demonstrate that, once one allows for positive trend inflation, the other components of the Fed’s response function also play a key role, along with the parameters of the model and the steady-state level of inflation. Thus, the apparent changes in the Fed’s response to the output gap, output growth and in interest smoothing each have consequences for determinacy. Interestingly, all three policy changes made by the Fed since the Volker disinflation —stronger response to output growth, more interest smoothing, and weaker response to output gap— will tend to make determinacy more likely.

We now turn to the determinacy implications of these Taylor rule estimates. Given that the Taylor principle is not sufficient to establish determinacy, estimating the parameters of the Taylor rule will in general be inadequate to answer the question of whether such a rule is consistent with a determinate equilibrium. Instead, we feed the estimated parameters from each Taylor rule into the model

\textsuperscript{26} To construct these p-values, we estimate a common Taylor rule over the whole sample (excluding 1979-82) with dummy variables for pre-79 coefficients and post-82 coefficients. We then use a Wald test to test the null of equality of long-run coefficients across time periods. Note that this approach yields identical point estimates as in Table 1, but very slightly different standard errors.
described and calibrated in Section II to examine the determinacy implications of monetary policy over the two samples. In this exercise, we continue to assume, for now, that firms update prices approximately every 7 months on average (\(\theta_{sp}=.55\)). We first consider whether the model yields a determinate rational expectations equilibrium (REE) given the estimated parameters of the Taylor rule for two steady-state inflation rates – 3% and 6% – designed to replicate average inflation rates in each of the two time periods.\(^{27}\) In addition, we consider how determinacy varies over the distribution of our parameter estimates. For each type of Taylor rule, we draw 10,000 times from the distribution of the estimated parameters and assess the fraction of draws that yield a determinate rational expectations equilibrium at 3% and 6% steady-state levels of inflation. The results are presented in the bottom panel of Table 1.

First, we find that the pre-1979 response of the central bank implied an indeterminate REE given the inflation rate of that time (6%). This is a very robust implication of the Taylor rule estimates, with less than two percent of the distribution of parameter estimates yielding a determinate REE equilibrium for any of the estimated Taylor rules. On the other hand, the post-1982 response is consistent with a determinate REE at the low inflation rates of this period (3%). Using our preferred specification, the mixed Taylor rule, more than 90% of the empirical distribution of parameters yields determinacy. Thus, like Taylor (1999), Clarida et al (2000) and others, we find that monetary policy before Volker led to indeterminacy in the 1970s, but that since 1982 the Fed’s response has helped ensure determinacy.

Our approach also allows us to assess the relative importance of the change in the Fed’s response function versus the change in steady-state inflation in altering the determinacy status of the economy. For example, we note that had the Fed maintained its pre-1979 response function but had lowered average inflation from 6% to 3% per year (via a change in the inflation target in the Taylor rule), the US economy would have remained in the indeterminacy region of the parameter space. Thus, the Volker disinflation, during which average inflation was brought down, would have been insufficient to guarantee determinacy without a change in the Fed’s response function as well. Similarly, we also find that the Fed’s response to macroeconomic variables since 1982, while consistent with determinacy at 3% inflation rate, is only marginally consistent with determinacy at the inflation rate of the 1970s. Specifically, while the estimated parameters of each specification yield a determinate REE at a 6% steady-state rate of inflation, only a little above half of the distribution of estimated parameters is consistent with determinacy at this inflation rate according to the mixed Taylor rule estimates. Thus, the estimated parameters are on the edge of the parameter space consistent with a unique REE. This implies that if the Fed in the 1970s had simply switched to the current policy rule without simultaneously engaging in the Volker disinflation, it is quite possible that the US economy would have remained subject to self-fulfilling expectations-driven

\(^{27}\) Before feeding estimated parameters into the model, we first convert the interest smoothing parameter into a quarterly frequency using the same approach as described in footnote 24.
fluctuations. The shift from indeterminacy to determinacy thus appears to have been due to two major policy changes: a change in the policy rule and a decline in the inflation target of the Federal Reserve during the Volker disinflation. Either one done individually would likely have been insufficient to move the economy from indeterminacy to determinacy.

4.2 Counterfactual Experiments

The results of the previous section indicate that changes in monetary policy around the Volker disinflation likely moved the US economy from a state of indeterminacy to one of determinacy, as originally argued by Taylor (1999) and Clarida et al (2000) and more recently reemphasized by Lubik and Schorfheide (2004) and Boivin and Giannoni (2006). While previous work has focused almost exclusively on the Fed’s response to inflation, we’ve shown that the Fed has also significantly changed its response to the output gap, output growth, and the degree of interest smoothing.

In this section, we perform counterfactual experiments designed to differentiate between the contributions of each policy change for determinacy. To answer how quantitatively important is each policy change, we consider the following set of experiments. First, for each period’s policy rule, we draw from the empirical distribution of estimated parameters and calculate the fraction of draws that yield a determinate equilibrium at 3% and 6% inflation rates, this replicates the exercise in Table 1 and serves as the baseline for this section’s analysis. Then, we repeat the procedure but switch, in turn, the period-specific coefficients on inflation, interest smoothing, output growth and the output gap. We continue to use Calvo price setting with average price duration halfway between Bils and Klenow (2004) and Nakamura and Steinson (forthcoming).

The results are presented in Table 2. Consider first the effect of switching the inflation response. For the pre-1979 period at 6% inflation, this has no effect on determinacy, meaning that the fraction of draws from the empirical distribution of parameter estimates yielding a determinate REE is unchanged at 0%. This means that if the only policy change enacted by the Fed had been to raise its response to inflation to the post-1982 level, but leaving its other response coefficients and the steady-state rate of inflation unchanged, the US economy would have remained in an indeterminate equilibrium. Thus, our findings do not support the argument of Clarida et al (2000) that the change in the Fed’s response to inflation, by itself, was enough to shift the US economy out of the indeterminacy of the 1970s. However, this policy change combined with the Volker disinflation can account for much of the movement away from indeterminacy. Specifically, we find that if the Fed had maintained its pre-Volker policy rule but

28 Specifically, we draw from each time period’s distribution of parameters, leaving the covariance matrix unchanged but altering the mean of the relevant parameter to match that of the other time sample.
used the post-1982 inflation response, then this single policy switch combined with the Volker disinflation would have raised the likelihood of determinacy to about two-thirds.

We also consider the implication of switching the degree of interest smoothing across periods and the response to output growth, both of which are statistically different in the two time periods (see Table 1). For interest smoothing, we find almost identical results as in the baseline case, indicating that the increased inertia of interest rate decisions since the Volker disinflation cannot account for the switch in determinacy across periods. Switching the response to output growth across the two periods has a more important effect: the fraction of draws yielding determinacy in the post-1982 period at 3% (6%) inflation would have been only 76.3% (15%) instead of 91.2% (55%) if the response to output growth had remained unchanged. On the other hand, starting from the pre-1979 policy rule and raising the response to output growth to the post-1982 level has almost no effect on determinacy. This indicates that the change in the response to output growth complemented the other policy changes in terms of restoring determinacy, but could not, by itself, account for the reversal in determinacy around the time of the Volker disinflation.

Finally, we consider the effect of the change in the Fed’s response to the output gap, a policy difference strongly emphasized by Orphanides (2004). The results are very similar to those with output growth, but quantitatively even more important. In particular, if the post-1982 Fed had responded as strongly to the output gap as they did before Volker, then the likelihood that the US economy would still be in the indeterminacy region would be much higher. We find that less than less than two-thirds of draws from the empirical distribution of Taylor rule estimates would be consistent with a determinate REE at 3% inflation using the post-1982 rule with the pre-1979 output gap response. At 6% inflation, the fraction of draws yielding determinacy goes from 55% to 20%. Thus, this result supports the emphasis placed by Orphanides (2004) on the lower response to the output gap by the Fed since the Volker era, but for a different reason. Orphanides emphasizes that if the output gap is mismeasured in real-time, then a strong response to the output gap, like that followed by the Fed in the 1970s, can be destabilizing. Our interpretation is instead that even if the output gap is perfectly measured by the central bank, strong responses to the output gap can be destabilizing by raising the probability of indeterminacy.

Nonetheless, one result that continues to stand out from Table 2 is that none of the individual changes in the Fed’s reaction function, nor even all of them combined, would have been enough to shift the US economy far from the indeterminacy region. Instead, achieving determinacy also required a decline in the steady-state level of inflation. This decline in trend inflation, done largely in the Volker disinflation, thus also played a crucial role in stabilizing the economy. But like the changes in the Fed’s reaction function, the disinflation would not by itself have been sufficient to move the economy out of
indeterminacy, as can be seen by comparing the baseline results using the pre-1979 rule under 6% and 3% inflation.

Using this counterfactual approach, we can also investigate how the central bank can further minimize the likelihood of indeterminacy. Thus, we consider determinacy prospects using each policy rule but imposing that the output gap response be zero.\textsuperscript{29} In the post-1982 period, eliminating the response to the output gap would raise the likelihood of determinacy significantly. At 3% inflation, 96.2% of draws are consistent with a unique REE equilibrium when we impose zero response to the output gap, and the proportion at 6% inflation is 92%. This is a dramatic improvement from 55% of draws that yield determinacy using the post-1982 Taylor rule at 6% inflation. Thus, while the Fed has clearly improved determinacy prospects by reducing its response to the output gap since the 1970s, a complete elimination of this response would be better yet, even when we assume that the output gap is perfectly measured.

Importantly, this does not imply that the Federal Reserve is best served by not responding to the real side of the economy. Consider the counterfactual of no response by the Fed to both the output gap and output growth in each time period. In the post-1982 period, the prospects for determinacy are lower than in the case with just zero response to output gap, particularly at higher inflation rates. For the latter, eliminating any response to the real side of the economy yields determinacy in less than 9% of draws, instead of the 92% when only the response to the output gap is eliminated. Thus, the current strong response to output growth by the Federal Reserve is well-justified, and would play an important stabilizing role were the Fed to completely eliminate responding to the output gap. Furthermore, a positive response to the real side of the economy should not be interpreted as central bankers being ‘dovish’ on inflation.

4.3 Robustness Analysis

In this section, we pursue some robustness checks on our results. The fact that higher steady-state inflation raises the likelihood of indeterminacy reflects the increased importance of forward-looking behavior in firms’ price setting decisions. Thus, we primarily focus on assumptions that strongly affect how forward-looking pricing decisions are. First, we consider sensitivity to the degree of price stickiness. When firms reset prices in the Calvo model, the weight placed on future profits depends strongly on how likely a firm is to not have altered its price by that period. Thus, greater price stickiness will naturally increase the sensitivity of reset prices to expectations of future macroeconomic variables. As a result, one

\textsuperscript{29} Here, we draw from each period’s distribution of parameters, then impose that the relevant coefficient be exactly zero for each draw.
would expect indeterminacy to become increasingly difficult to eliminate as the degree of price rigidity rises.

To see whether this is indeed the case, we consider two alternative degree of price stickiness. First, we follow Bils and Klenow (2004) who find that firms update prices every 4 to 5 months on average and reproduce our results using $\theta_{sp} = 0.40$. Second, we follow Nakamura and Steinson (forthcoming) who find much longer durations of price rigidity, with firms going between 8 and 11 months between price changes on average. In this case, we set $\theta_{sp} = 0.70$. We reproduce the determinacy results of the previous section in Table 3 using the mixed Taylor rule for each time period. Under the Bils and Klenow case, we continue to find that the post-1982 policy was consistent with determinacy at low inflation rates, while the pre-Volker policy was generally inconsistent with determinacy at a 6% inflation rate. Nonetheless, we can see that determinacy is more easily sustained under lower levels of price rigidity by the fact that the fraction of the empirical distribution yielding determinacy is consistently higher than in the baseline case. In addition, using this lower rate of price-stickiness implies that determinacy would have been achieved solely through the change in the Fed’s response to macroeconomic variables. Using the degree of price stickiness from Nakamura and Steinson moves all of the quantitative results in the opposite direction. For the pre-Volker era, the results are qualitatively similar to our baseline findings, with indeterminacy occurring consistently at both inflation rates. However, with this higher degree of price stickiness, we now find that even the current policy rule is likely inconsistent with determinacy, even at 3% inflation, with less than 50% of the empirical distribution of Taylor rule estimates yielding a determinate REE equilibrium.

Clearly, the degree of price stickiness plays an important role in determinacy conditions. However, the importance of this variable is likely overestimated under Calvo pricing. This setup forces firms to place some weight on possible future outcomes in which their relative price would be so unprofitable that “real world” firms would choose to pay a menu cost and reset their price. An alternative approach to Calvo pricing is the staggered contracts approach of Taylor (1977) in which firms set prices for a pre-determined duration of time. This pricing assumption can loosely be thought of as a lower bound on forward-looking behavior (conditional on price durations) since it imposes zero weight on expected profits beyond those of the contract length in the firm’s reset price optimization. We replicate our results using staggered pricing with firms setting prices for three quarters and display the results in Table 3. For the pre-Volker era, the results again largely point to indeterminacy at high levels of inflation. However, the post-1982 policy rule is now consistent with determinacy at both 3% and 6% inflation rates. In fact, the results using staggered price setting with duration of 9 months are very close

Another way to see this limitation of the Calvo model is to note that using Nakamura and Steinson rates of price-setting, the Calvo model breaks down at an inflation rate of 6.1%.
to those using Calvo price setting with average price duration of 5 months. This reflects the shortened time horizon of price-setting firms with staggered contracts and the concurrent decrease in the importance of expectations of future outcomes relative to the Calvo case. We interpret Taylor pricing as being a lower bound on determinacy issues (conditional on average price durations) and Calvo pricing as an upper bound. Despite the sensitivity of determinacy results to these variations, what seems clear is that the U.S. economy was in an indeterminate region of the parameter space in the pre-Volker era given the high average inflation of that time, but moved into the determinacy region after 1982. The relative importance of the decrease in steady-state inflation versus the changes in the Fed’s response to macroeconomic conditions, on the other hand, is sensitive to the price-setting model and average price durations used. In the absence of definitive evidence favoring one modeling approach over the other along with clearer results on how sticky prices actually are in the data, we are unable to decisively measure the relative importance of these two monetary policy changes.

Recent research on sticky price models commonly augments the basic Calvo setup with price indexation (see Yun (1996) and Christiano et al (2005)). In such a setup, firms automatically adjust their price by some fraction of steady-state inflation (or lagged inflation) in between optimizing price updates, thereby increasing the persistence of the inflation process. Our baseline model does not include this feature for two reasons. First, any price indexation implies that firms are constantly changing prices, a feature strongly at odds with the empirical findings of Bils and Klenow (2004) and more recently Nakamura and Steinson (forthcoming), among many others. Second, while this feature is often included to replicate the apparent role for lagged inflation in empirical estimates of the NKPC (see Clarida et al 1999), Cogley and Sbordone (forthcoming) show that once one controls for trend inflation, estimates of the NKPC reject the presence of indexation in price setting decisions. Nonetheless, because this feature is so prevalent in the literature, we briefly discuss how it affects our results.

Ascari and Ropele (2007) have shown that allowing for indexation diminishes the determinacy issues that arise with positive trend inflation. The reason is that indexation decreases the devaluation of firms’ reset prices that comes from positive inflation. This tends to offset the need for more forward-looking behavior induced by positive trend inflation. In the special case of full indexation – firms raise their price fully with past or steady-state level of inflation – determinacy in the model becomes completely insensitive to trend inflation. We follow Yun (1996) and consider the case in which firms index their prices to steady state inflation by some fraction $\omega$, where $0 \leq \omega \leq 1$. One can readily show that the log-linearized equation for the relative reset price is unchanged but for the new coefficients:

$$y_1^* = \gamma_1 \pi^\omega (1 - \theta)$$

$$y_2^* = \gamma_2 \pi^{-\omega \theta (1 + \eta^{-1})}.$$ 

and the relationship between the reset price and inflation is now given by
In the special case of full-indexation ($\omega = 1$), then $\gamma_1^* = \gamma_2^*$ and the supply-side collapses to the standard NKPC.\(^{31}\)

We replicate our baseline empirical results on determinacy prospects based on our mixed Taylor rule estimates for each time period and for different levels of price indexation in Figure 5.\(^{32}\) The basic results of Ascari and Ropele (2007) is clear in Figure 5: as indexation rises, the fraction of the empirical distribution of Taylor rule estimates consistent with determinacy rises. Note that it takes fairly high levels of indexation to change our results substantially. For example, for the probability of determinacy to exceed 50% in the pre-1979 era at 6% inflation requires price indexation of more than 0.7. Thus, the idea from Clarida et al (2000) that the US economy was likely in an indeterminacy region pre-Volker but not thereafter is robust to substantial levels of price indexation. However, the importance of taking into account positive trend inflation to reach this conclusion is also clearly illustrated in Figure 5. This can be seen by examining the results with full price indexation ($\omega = 1$), in which case the supply-side of the model is observationally equivalent to the NKPC with zero trend inflation.\(^{33}\) In this case, the distribution of the estimated parameters of the Taylor rule are largely consistent with determinacy in both time periods: 96% of draws in the post-1982 period yield a determinate REE and 81% of draws do so in the pre-1979 era.

An additional extension to the basic model which is frequently added is habit formation. This introduces additional persistence in output and helps match some properties of the data (Fuhrer (2000)). To consider the implications of habit formation for our results, we replace the consumer’s objective function with the following

$$\max E_t \sum_{j=0}^{\infty} \beta^j \left[ \ln \left( \frac{C_{t+j}}{H_{t+j}} \right) - (1 + \eta^{-1})^{-1} \int_0^1 N(i)^{1+\eta^{-1}} \right]$$

where the consumer treats the stock of habit $H_t$ as exogenously determined (“external” habit) but is equal to lagged consumption. The parameter $h$ determines the importance of habit formation in consumption decisions. While estimated degrees of habit formation vary widely, we choose a value from the upper end of the estimated spectrum, $h = 0.9$, as a robustness check. We replicate the determinacy results from the

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\(^{31}\) Allowing for indexation to past inflation changes the reset price equation by also introducing lagged inflation. However, the results for determinacy are very similar to those with indexation to steady-state inflation.

\(^{32}\) We continue to assume $\theta_s=0.55$, although another drawback of introducing indexation into a model is that it is unclear how to link price stickiness from the micro data to price setting models with indexation in which firms are continuously changing prices. Figure 5 is based on making 10,000 draws from the empirical distribution of Taylor rule estimates over each period, for each degree of price indexation considered (0 to 1 by increments of 0.01).

\(^{33}\) This is why, for each time period, the 3% and 6% lines converge to the same value when $\omega = 1$. 

26
previous section using baseline parameters and habit formation in Table 3. The results are almost identical to our baseline case.

We also consider an empirical robustness issue: the real-time measurement of the output gap. Real-time estimates of the output gap are very noisy and sensitive to how the gap is measured, a point emphasized by Orphanides and van Norden (2002). But in the absence of the historical output gap measure actually used by the Fed, one is left with only proxies. Our baseline approach was to apply a linear time trend with a break in 1973 to the log of real GDP, for each period of our sample using real-time data. As an alternative, we consider here the use of a quadratic time trend, again using real-time data. The implications of this alternative measure of the output gap for determinacy are presented in Table 3. The results are qualitatively similar to our baseline approach, with the exception of post-1982 results with 6% inflation, in which only a small fraction of draws (around 20%) from the distribution of parameter estimates yields determinacy. We also tried using the HP-filter on real-time data to extract an output gap series and got qualitatively similar results for determinacy but much less precise estimates of the Taylor rule.

Finally, we examine how potential differences in the PLT response for pre-1979 and post-1982 periods affect determinacy results. Following Gorodnichenko and Shapiro (2007), we introduce an element of (partial) price level targeting into the Taylor rule and after estimating this modified rule, we compute the fraction of cases with a determinate equilibrium. Because PLT and AR(2) interest rate smoothing have very similar reduced form estimates, our determinacy results survive this robustness check as well.

V- Conclusion

This paper sheds new light on the sources of the significant decrease in macroeconomic volatility since the early 1980s commonly referred to as the Great Moderation. First, we confirm the original insight of Clarida et al (2000) that the US economy moved from the indeterminacy region in the 1970s to determinacy since the early 1980s because of changes in monetary policy. This point of view has been challenged in a series of papers by Orphanides (2001,2002,2004) which argued that the Fed, in fact, satisfied the Taylor principle in both periods and that the US economy could therefore not have been in an indeterminate region in the 1970s. Instead, Orphanides emphasized the Fed’s decreased response to the (mismeasured) output gap since Volker’s accession as chairman of the Fed as a primary source of economic stabilization. Building on recent work by Ascarí and Ropele (2007), Kiley (2007) and Hornstein and Wolman (2005) showing that the Taylor principle does not guarantee determinacy when trend inflation is positive, we argue that while the Fed may indeed have satisfied the Taylor principle in
the pre-Volker era, the US economy was still subject to sunspot fluctuations in the 1970s given the high average rate of inflation over this time period, as well as the Fed’s response to both inflation and the real side of the economy.

Our basic findings thus provide additional support for the well-known view that monetary policy changes have likely played an important element in accounting for the Great Moderation. However, the specific policy changes that we emphasize differ from the consensus monetary policy interpretation. One novel finding is that the Volker disinflation, the period from 1979-1982 in which the Fed abandoned interest rate targeting, very likely played a key role in restoring macroeconomic stability through its effect on the steady-state level of inflation. Thus, our results strongly support the emphasis placed by some recent work on studying the determinants of trend inflation, such as Primiceri (2006), Cogley et al (2008), and Ireland (forthcoming), and complements the finding of Cogley and Sbordone (forthcoming) that accounting for trend inflation has important implications for estimates of the New Keynesian Phillips Curve.

In addition, while most research has emphasized the central bank’s response to inflation as the key determinant for determinacy, our results move the Fed’s response to the real side of the economy to center stage. Specifically, we find that the Fed’s decreased response to the output gap since the 1970s has played an important stabilizing role, but not only because of the real-time mismeasurement issue emphasized by Orphanides (2002). Under positive trend inflation, responding to the output gap –even if perfectly measured– can be destabilizing in theory and, in fact, the Fed’s reduced response to the gap empirically accounts for a significant component of the movement away from indeterminacy since the Volker disinflation. Yet whereas previous research has approvingly noted this policy change as a sign of the Fed’s increased commitment to inflation-fighting and economic stability in general, we also uncover the novel finding that the Fed has compensated its reduced response to the gap with a strong increase in its response to output growth. Thus, contrary to previous work, we find little evidence that the Fed is less sensitive to the real side of the economy; rather it has altered the primary measure of the real side of the economy to which it responds. We show that, in theory, responding to output growth can help restore determinacy under positive trend inflation and that, empirically, the strong response of the Fed to output growth since the Volker disinflation has also played an important role in moving the economy toward determinacy.

Our theoretical and empirical results lead to policy prescriptions which differ qualitatively and quantitatively from views commonly held in academic and policy circles. We believe that the issues raised in the present paper deserve further investigation as well as careful attention from policymakers because there remains a non-negligible (albeit smaller than before) chance that an indeterminacy-driven inflation spiral could still occur.
References


Ireland, Peter, “Changes in the Federal Reserve’s Inflation Target: Causes and Consequences,” forthcoming in *Journal of Money, Credit, and Banking*.


Figure 1: Determinacy in a New Keynesian Model with Calvo Pricing for Positive Steady State Inflation Rates: Basic Taylor Rules

Note: Steady-state inflation rate is on horizontal axis. The response to inflation in the Taylor rule is on vertical axis. The basic Taylor rule has zero response to output gap and output growth rate as well as no interest rate smoothing. The model and calibration of parameter is described in the text.
Figure 2: Determinacy in a New Keynesian Model with Calvo Pricing for Positive Steady State Inflation Rates: Responding to Output Gap

Note: Steady-state inflation rate is on horizontal axis. The response to inflation in the Taylor rule is on vertical axis. Lines in the figure correspond to different values of the response to output gap in the Taylor rule. The basic Taylor rule has zero response to output growth rate as well as no interest rate smoothing. The model and calibration of parameter is described in the text.
Figure 3: Determinacy in a New Keynesian Model with Calvo Pricing for Positive Steady State Inflation Rates: Responding to Output Growth

Note: Steady-state inflation rate is on horizontal axis. The response to inflation in the Taylor rule is on vertical axis. Lines in the figure correspond to different values of the response to output growth rate in the Taylor rule. The basic Taylor rule has zero response to output gap as well as no interest rate smoothing. The model and calibration of parameter is described in the text.
Figure 4: Determinacy in a New Keynesian Model with Calvo Pricing for Positive Steady State Inflation Rates: Interest Smoothing

Note: Steady-state inflation rate is on horizontal axis. The response to inflation in the Taylor rule is on vertical axis. Lines in the figure correspond to different values of interest rate smoothing. The basic Taylor rule has zero response to output gap and output growth rate. The model and calibration of parameter is described in the text.
Figure 5: Effect of Price Indexation on Determinacy Results

Note: Blue thin lines are post-1982 Taylor rule. Black thick lines are pre-1979 Taylor rule. Solid lines are at 3% inflation, dashed lines are at 6% inflation.
### Table 1: Reduced Form Estimates of Taylor Rule

<table>
<thead>
<tr>
<th></th>
<th>Contemporaneous Taylor Rule</th>
<th></th>
<th>Forward-Looking Taylor Rule</th>
<th></th>
<th>Mixed Taylor Rule</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \phi_{1,x} )</td>
<td>0.80***</td>
<td>1.19***</td>
<td>0.42</td>
<td></td>
<td>1.44**</td>
</tr>
<tr>
<td></td>
<td>(0.23)</td>
<td>(0.41)</td>
<td></td>
<td></td>
<td>(0.57)</td>
</tr>
<tr>
<td>( \phi_{1,\pi} )</td>
<td>-0.02</td>
<td>1.91**</td>
<td>0.02</td>
<td></td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>(0.10)</td>
<td>(0.82)</td>
<td></td>
<td></td>
<td>(0.36)</td>
</tr>
<tr>
<td>( \phi_{1,\gamma} )</td>
<td>0.55***</td>
<td>0.14</td>
<td>0.06</td>
<td></td>
<td>0.85**</td>
</tr>
<tr>
<td></td>
<td>(0.12)</td>
<td>(0.17)</td>
<td></td>
<td></td>
<td>(0.33)</td>
</tr>
<tr>
<td>( \rho_1 )</td>
<td>1.38***</td>
<td>1.16***</td>
<td>0.56</td>
<td></td>
<td>1.29***</td>
</tr>
<tr>
<td></td>
<td>(0.09)</td>
<td>(0.09)</td>
<td></td>
<td></td>
<td>(0.09)</td>
</tr>
<tr>
<td>( \rho_2 )</td>
<td>-0.50***</td>
<td>-0.22**</td>
<td>-0.56</td>
<td></td>
<td>-0.37***</td>
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<tr>
<td></td>
<td>(0.09)</td>
<td>(0.10)</td>
<td></td>
<td></td>
<td>(0.09)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>R²</th>
<th>s.e.e.</th>
<th>( \rho_1 + \rho_2 )</th>
<th>Determinacy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.97</td>
<td>0.98</td>
<td>0.56</td>
<td>0.89</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Determinacy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3% inflation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fraction at 3%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6% inflation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fraction at 6%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0%</td>
</tr>
</tbody>
</table>

Note: The top panel reports NLS estimates of the Taylor rule. Newey-West HAC standard errors are in parentheses. **, *** indicates statistical significance at the 10%, 5%, and 1% level respectively. \( P-val \) is the p-value of the null that the long-run responses are the same across the two periods. \( \phi_{1,\pi} \) corresponds to the average forecast of the next 2 quarters in Taylor rule estimated in equation (6). \( \phi_{1,\gamma} \) corresponds to \( j = 0 \) in Taylor rule estimated in equation (6). \( \rho_1 + \rho_2 \) is adjusted to quarterly frequency because pre-1979 and post-1982 periods have different frequency of FOMC meetings. See footnote 24 for more details. The bottom panel reports whether the estimated coefficients are consistent with a unique REE for steady state inflation rates of 3% and 6%. ‘Yes’/’No’ shows whether there is a determinate rational expectations equilibrium when the policy reaction function rule is evaluated at point estimates of the Taylor rule. \( Fraction at x\% \) is the fraction of draws from the distribution of estimated parameters which yield a unique REE at the specified inflation rate. 10,000 draws were used to compute the fraction of cases with indeterminate solutions. For each draw, parameters of a Taylor rule are taken from the joint asymptotical normal distribution based on least squares estimates of Taylor rules.
Table 2: Counterfactual Experiments

<table>
<thead>
<tr>
<th></th>
<th>Taylor rule parameters</th>
<th>Steady state inflation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\phi_\pi$ $\phi_{gy}$ $\phi_x$ $\rho_1$ $\rho_2$</td>
<td>3% 6%</td>
</tr>
<tr>
<td>Pre-1979 period</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline Taylor Rule Estimates</td>
<td>1.25 -0.18 0.74 1.30 -0.41</td>
<td>9.5% 0.0%</td>
</tr>
<tr>
<td>Switch Inflation Response</td>
<td>1.68 -0.18 0.74 1.30 -0.41</td>
<td>65.9% 0.0%</td>
</tr>
<tr>
<td>Switch Interest Smoothing Parameters</td>
<td>1.25 -0.18 0.74 1.11 -0.20</td>
<td>10.1% 0.0%</td>
</tr>
<tr>
<td>Switch Output Growth Response</td>
<td>1.25 1.29 0.74 1.30 -0.41</td>
<td>10.2% 0.0%</td>
</tr>
<tr>
<td>Switch Output Gap Response</td>
<td>1.25 -0.18 0.24 1.30 -0.41</td>
<td>22.1% 0.0%</td>
</tr>
<tr>
<td>Zero Output Gap Response</td>
<td>1.25 -0.18 0 1.30 -0.41</td>
<td>2.9% 0.0%</td>
</tr>
<tr>
<td>Zero Output Gap and Output Growth Response</td>
<td>1.25 0 0 1.30 -0.41</td>
<td>5.1% 0.0%</td>
</tr>
<tr>
<td>Post-1982 period</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline Taylor Rule Estimates</td>
<td>1.68 1.29 0.24 1.11 -0.20</td>
<td>91.3% 54.6%</td>
</tr>
<tr>
<td>Switch Inflation Response</td>
<td>1.25 1.29 0.24 1.11 -0.20</td>
<td>57.6% 18.4%</td>
</tr>
<tr>
<td>Switch Interest Smoothing Parameters</td>
<td>1.68 1.29 0.24 1.30 -0.41</td>
<td>90.9% 54.3%</td>
</tr>
<tr>
<td>Switch Output Growth Response</td>
<td>1.68 -0.18 0.24 1.11 -0.20</td>
<td>76.3% 15.0%</td>
</tr>
<tr>
<td>Switch Output Gap Response</td>
<td>1.68 1.29 0.74 1.11 -0.20</td>
<td>63.2% 20.0%</td>
</tr>
<tr>
<td>Zero Output Gap Response</td>
<td>1.68 1.29 0 1.11 -0.20</td>
<td>96.2% 92.2%</td>
</tr>
<tr>
<td>Zero Output Gap and Output Growth Response</td>
<td>1.68 0 0 1.11 -0.20</td>
<td>87.9% 8.4%</td>
</tr>
</tbody>
</table>

Note: This table lists determinacy results for the 1969-1978 period and the 1983-2002 period for steady-state inflation rates of 3% and 6%. Baseline Taylor Rule Estimates refers to the case in which the estimated parameters of the mixed Taylor rule from Table 1 are plugged into the model. Switching means using the coefficient from the other period's estimated rule and keeping the other parameters of the rule unchanged. Parameter values in bold show the coefficient for which the value is modified. 10,000 draws were used to compute the fraction of cases with indeterminate solutions. For each draw, parameters of a Taylor rule are taken from the joint asymptotical normal distribution based on least squares estimates of Taylor rules.
Table 3: Robustness of Determinacy Results

<table>
<thead>
<tr>
<th>Case</th>
<th>Pre-1979 period</th>
<th>Post-1982 period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Determinacy at point estimates</td>
<td>Fraction of determinate equilibria given sampling uncertainty</td>
</tr>
<tr>
<td>Bils and Klenow Case (change prices every 5 months)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3% inflation</td>
<td>Yes</td>
<td>56.5%</td>
</tr>
<tr>
<td>6% inflation</td>
<td>No</td>
<td>7.4%</td>
</tr>
<tr>
<td>Nakamura and Steinson Case (change prices every 10 months)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3% inflation</td>
<td>No</td>
<td>0.0%</td>
</tr>
<tr>
<td>6% inflation</td>
<td>No</td>
<td>0.0%</td>
</tr>
<tr>
<td>Taylor Staggered Price Setting (duration of 9 months)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3% inflation</td>
<td>Yes</td>
<td>57.3%</td>
</tr>
<tr>
<td>6% inflation</td>
<td>No</td>
<td>16.9%</td>
</tr>
<tr>
<td>Baseline with habit formation ($h = .9$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3% inflation</td>
<td>No</td>
<td>10.0%</td>
</tr>
<tr>
<td>6% inflation</td>
<td>No</td>
<td>0.0%</td>
</tr>
<tr>
<td>Alternative Measure of Real-Time Output Gap (quadratic trend)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3% inflation</td>
<td>No</td>
<td>0.4%</td>
</tr>
<tr>
<td>6% inflation</td>
<td>No</td>
<td>0.1%</td>
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<tr>
<td>Taylor rules with price level targeting</td>
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<tr>
<td>3% inflation</td>
<td>No</td>
<td>14.3%</td>
</tr>
<tr>
<td>6% inflation</td>
<td>No</td>
<td>0.2%</td>
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Note: The table presents robustness results of determinacy from Table 2. ‘Yes’/’No’ shows whether there is a determinate rational expectations equilibrium when the policy reaction function rule is evaluated at point estimates of the Taylor rule. 10,000 draws were used to compute the fraction of cases with indeterminate solutions. For each draw, parameters of a Taylor rule are taken from the joint asymptotical normal distribution based on least squares estimates of Taylor rules.
Appendix Figure 1: Determinacy in a New Keynesian Model with Taylor Staggered Pricing for Positive SS Inflation Rates: Basic Taylor Rules

Note: Steady-state inflation rate is on horizontal axis. The response to inflation in the Taylor rule is on vertical axis. The basic Taylor rule has zero response to output gap and output growth rate as well as no interest rate smoothing. The model and calibration of parameter is described in the text.
Note: Steady-state inflation rate is on horizontal axis. The response to inflation in the Taylor rule is on vertical axis. Lines in the figure correspond to different values of the response to output gap in the Taylor rule. The basic Taylor rule has zero response to output growth rate as well as no interest rate smoothing. The model and calibration of parameter is described in the text.
Appendix Figure 3: Determinacy in a New Keynesian Model with Staggered Pricing for Positive SS Inflation Rates: Responding to Output Growth

Note: Steady-state inflation rate is on horizontal axis. The response to inflation in the Taylor rule is on vertical axis. Lines in the figure correspond to different values of the response to output growth rate in the Taylor rule. The basic Taylor rule has zero response to output gap as well as no interest rate smoothing. The model and calibration of parameter is described in the text.
Appendix Figure 4: Determinacy in a New Keynesian Model with Staggered Pricing for Positive SS Inflation Rates: Interest Smoothing

Note: Steady-state inflation rate is on horizontal axis. The response to inflation in the Taylor rule is on vertical axis. Lines in the figure correspond to different values of interest rate smoothing. The basic Taylor rule has zero response to output gap and output growth rate. The model and calibration of parameter is described in the text.