

NBER WORKING PAPER SERIES

MONETARY POLICY, TREND INFLATION AND THE GREAT MODERATION:
AN ALTERNATIVE INTERPRETATION

Olivier Coibion
Yuriy Gorodnichenko

Working Paper 14621
<http://www.nber.org/papers/w14621>

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
December 2008

We are grateful to Jean Boivin, Kathryn Dominguez, Jordi Gali, Pierre-Olivier Gourinchas, David Romer, and Carl Walsh, as well as seminar participants at the Bank of Canada and UC Berkeley for comments. The views expressed herein are those of the author(s) and do not necessarily reflect the views of the National Bureau of Economic Research.

© 2008 by Olivier Coibion and Yuriy Gorodnichenko . All rights reserved. Short sections of text, not to exceed two paragraphs, may be quoted without explicit permission provided that full credit, including © notice, is given to the source.

Monetary Policy, Trend Inflation and the Great Moderation: An Alternative Interpretation
Olivier Coibion and Yuriy Gorodnichenko
NBER Working Paper No. 14621
December 2008
JEL No. C22,E3,E43,E5

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 Volcker disinflation to find that 1) while the Fed satisfied the Taylor principle in the pre-Volcker 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 Volcker disinflation, the US economy nonetheless moved from indeterminacy to determinacy in this time period, and 3) 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 Volcker disinflation.

Olivier Coibion
Department of Economics
College of William and Mary
115 Morton Hall
Williamsburg, VA 23188
ocoibion@wm.edu

Yuriy Gorodnichenko
Department of Economics
549 Evans Hall #3880
University of California, Berkeley
Berkeley, CA 94720-3880
and NBER
ygorodni@econ.berkeley.edu

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 Volcker as Federal Reserve chairman in 1979.¹ 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 Volcker 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-Volcker era responded to inflation in much the same way as those in the Volcker 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 Volcker, 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.²

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 (“dovish”) 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.³ 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 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

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).

Taylor principle after Volcker 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 Volcker 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 Volcker 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 Volcker 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 empirical feature of interest-rate decision-making.⁵ 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.

⁴ Super-inertial rules continue to guarantee determinacy, as with zero steady-state inflation.

⁵ See Clarida et al (2000) or Blinder and Reis (2005) for example.

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 Volcker 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. First, the persistence of interest rate changes has gone up. Second, like Orphanides (2003), we find that the Fed significantly reduced its response to the output gap but 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 Volcker 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. These 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 Volcker 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 Volcker disinflation.⁶ 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 due to several factors, none of which would likely have sufficed on their own. For example, taking the Fed's pre-Volcker 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-Volcker 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

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 4.1.

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

controlling for trend inflation has important implications in the estimation of the New Keynesian Phillips Curve, we conclude that accounting for trend inflation is necessary to properly assess the effectiveness of monetary policy in stabilizing the economy. In a sense, one may associate the end of the Great Inflation as one source of the Great Moderation. To support this notion, we document robust cross-country empirical evidence supporting a positive link between trend inflation and GDP volatility. Devoting more effort to understanding the determinants of trend inflation, as in Sargent (1999), Primiceri (2006) or Ireland (2007), and the Volcker 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-Volcker 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 the 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-Volcker 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 after 1982 could be inconsistent with determinacy at 1970s-level inflation rates begs the question of how policy-makers could alter this situation. In our counterfactual experiments, 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 Volcker, the Fed has been responding strongly to output growth. Were the Fed to stop responding to both 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.⁸ Thus, their models do not take into account the effects on determinacy of the lower steady-state inflation brought about by the Volcker disinflation. Second, we consider a larger set of

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.

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 4.3.

policy responses for the central bank, which we argue has significant implications for determinacy as well.⁹ 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 misspecified, this can affect all of the other estimated parameters.¹⁰ 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 for any model.¹¹ 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 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. We use the model to illustrate the importance of positive steady state inflation for determinacy of REE and point to mechanisms that can enlarge or reduce the region of determinacy for various policy rules.

2.1 The Model

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

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

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

$$C_{t+j} + \frac{S_{t+j}}{P_{t+j}} \leq \int_0^1 \frac{N(i)_{t+j} W(i)_{t+j}}{P_{t+j}} di + \frac{S_{t+j-1} R_{t+j-1}}{P_{t+j}} + T_{t+j}$$

⁹ For example, neither Lubik and Schorfheide (2004) nor Boivin and Giannoni (2006) 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.

where S 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 first order conditions for the consumer are given by

$$C_t N(i)_t^{1/\eta} = \frac{W(i)_t}{P_t}$$

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

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

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

where θ 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

$$P_t = \left[\int_0^1 P(i)_t^{1-\theta} di \right]^{1/(1-\theta)}$$

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 follows 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 λ 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

$$\max E_t \sum_{j=0}^{\infty} \lambda^j Q_{t,t+j} Y(i)_{t+j} [B(i)_t - MC(i)_{t+j}].$$

Substituting the firm's demand curve into the expression and maximizing with respect to $B(i)$ yields the first-order condition

$$\frac{B(i)_t}{P_t} = \frac{\theta}{\theta - 1} E_t \frac{\sum_{j=0}^{\infty} \lambda^j Q_{t,t+j} Y_{t+j} \left(\frac{P_{t+j}}{P_t}\right)^{\theta+1} \left(\frac{MC(i)_{t+j}}{P_{t+j}}\right)}{\sum_{j=0}^{\infty} \lambda^j Q_{t,t+j} Y_{t+j} \left(\frac{P_{t+j}}{P_t}\right)^{\theta}}.$$

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

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

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

$$Y_t^f = \left(\frac{\theta - 1}{\theta}\right)^{1/(1+\eta^{-1})} A_t.$$

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

$$Q_{t,t+j} = \frac{\beta^j Y_t P_t}{Y_{t+j} P_{t+j}} = \prod_{i=1}^j R_{t+i-1}^{-1}.$$

Finally, defining $GY_t \equiv Y_t/Y_{t-1}$ as the growth rate of output and $\Pi_t \equiv P_t/P_{t-1}$ as the gross inflation rate, we can rewrite the expression for the relative reset price in terms of stationary variables

$$\left(\frac{B_t}{P_t}\right)^{1+\theta/\eta} = E_t \frac{\sum_{j=0}^{\infty} \lambda^j \left[\prod_{i=1}^j R_{t+i-1}^{-1} GY_{t+i} \Pi_{t+i}^{1+\theta(1+\eta^{-1})} \right] X_t^{1+\eta^{-1}}}{\sum_{j=0}^{\infty} \lambda^j \left[\prod_{i=1}^j R_{t+i-1}^{-1} GY_{t+i} \Pi_{t+i}^{\theta} \right]} \quad (1)$$

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

$$P_t^{1-\theta} = (1 - \lambda) B_t^{1-\theta} + \lambda P_{t-1}^{1-\theta}.$$

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

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

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 $\bar{\pi} \equiv (\bar{\Pi} - 1)$ to be greater than or equal to zero. This has no effect on the first-order conditions of the consumer's problem. We let lower-case letters denoted the log-

deviation of a variable from its steady-state value with b_t denoting the log-linearized reset price relative to price level. We can write the dynamic IS equation as

$$E_t g y_{t+1} = r_t - E_t \pi_{t+1}$$

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

$$g y_t = x_t - x_{t-1} + \varepsilon_t^A.$$

However, non-zero trend inflation has important effects on the linearization of the price-setting equations. First, positive trend inflation ($\bar{\pi} > 0$) implies that reset prices (relative to price level) will, on average, be higher than the average price level

$$\overline{\left(\frac{B}{P}\right)} = \left(\frac{1 - \lambda \bar{\Pi}^{\theta-1}}{1 - \lambda}\right)^{(1-\theta)^{-1}}$$

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

$$\pi_t = \left(\frac{1 - \lambda \bar{\Pi}^{\theta-1}}{\lambda \bar{\Pi}^{\theta-1}}\right) b_t$$

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

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

where $\gamma_1 \equiv \lambda \bar{R}^{-1} \bar{G} \bar{Y} \bar{\Pi}^{\theta}$ and $\gamma_2 \equiv \gamma_1 \bar{\Pi}^{1+\theta/\eta}$.¹² Note that under zero-trend inflation, $\gamma_2 = \gamma_1$. Consider how positive trend inflation affects the relative reset price. First, higher steady-state inflation raises γ_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 $\bar{\pi} > 0$,

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

steady-state inflation is zero, these two factors cancel out on average. Positive $\bar{\pi}$ 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 $\bar{\pi}$ 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 $\bar{\pi}$ 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

$$b_t = (1 + \theta/\eta)^{-1}(d_t - e_t)$$

where the variables d_t and e_t follow respectively

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

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

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, η , 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 ($\bar{G}Y = 1.015^{0.25}$), which matches the U.S. rate from 1969 to 2002. The elasticity of substitution θ is set to 10. Finally, the degree of price stickiness (λ) 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 Steinsson (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, expressed in log-deviations from steady-state values:

$$r_t = \phi_\pi E_t \pi_{t+j} \tag{2}$$

in which the central bank sets interest rates as a function of contemporaneous ($j=0$) or future ($j>0$) inflation.¹³ 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:

¹³ Our results for $j = -1$ are similar to results for $j = 0$ and hence are not reported.

$\phi_\pi > 1$.¹⁴ This result, commonly known as the 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 Taylor principle loses its potency in environments with positive trend inflation. Panel A in 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.¹⁵ 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 1.2 percent per year, the minimum response needed by the central bank starts to rise. 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 almost ten 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 finding is in line with Woodford (2008, p. 516) and others who report that purely forward-looking rules may be more subject to indeterminacy.¹⁶ In our case, the breakdown of the basic Taylor principle is amplified because of 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).¹⁷

In the rest of this section, we investigate how modifications of the basic Taylor rule 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 as follows

$$r_t = \phi_\pi E_t \pi_{t+j} + \phi_x E_t x_{t+j} \quad (3)$$

¹⁴ Forward-looking rules, $j \geq 1$, typically also place a constraint on the maximum value of ϕ_π to sustain a unique REE. See Woodford (2003, chapter 4).

¹⁵ 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.

¹⁶ Furthermore, Bullard and Mitra (2002) and Woodford (2003) show that making the response to expected inflation more aggressive can conflict with ensuring determinacy because there is an upper bound on how aggressive response to inflation can be in the region of determinacy. This explains why stronger responses to expected inflation do not expand the region of determinacy in the forward-looking rule.

¹⁷ Appendix Figure 1, Panel A, reproduces the baseline determinacy issue with staggered price setting (under the assumption that prices are set for 3 quarters), yielding qualitatively similar results.

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.¹⁸ 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 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. Panel B in Figure 1 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 to 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.¹⁹ 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

¹⁸ In our model, $\kappa \equiv (1 - \lambda)(1 - \beta\lambda)/[\lambda(1 + \theta\eta^{-1})]$.

¹⁹ In Panel B of Appendix Figure 1, we present analogous results using staggered contracts.

$$r_t = \phi_\pi E_t \pi_{t+j} + \phi_{gy} E_t g_{t+j} \quad (4)$$

Panel C in Figure 1 presents the minimum response to inflation needed by the central bank to ensure determinacy for different trend inflation rates and responses to output growth.²⁰ For contemporaneous Taylor rules, having the central bank respond to output growth helps ensure determinacy of the equilibrium, but this effect is much weaker under forward-looking Taylor rules. 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 both inflation and current output growth by more than one-for-one.

There are two channels through which responding to output growth helps achieve determinacy. First, responding to the output growth rate effectively makes the policy reaction function history-dependent because it responds to lagged output. Second, responding to output growth amplifies the central bank's response to inflation. To see this, consider a permanent increase in inflation $d\pi$. Substituting in for output growth using the dynamic IS equation and re-arranging yields the following expression for real interest rates, assuming that $\phi_{gy} < 1$,

$$dr - d\pi = \frac{\phi_\pi - 1}{1 - \phi_{gy}} d\pi.$$

Satisfying the Taylor principle, $\phi_\pi > 1$, ensures that the real interest rate rises with expected inflation. But, as demonstrated in section 3.1, this is generally not sufficient to establish determinacy with positive trend inflation. Allowing for a positive response to output growth, however, amplifies the magnitude of the response of real interest rates to expected inflation. This is because when expected inflation rises, the real interest rate rises as long as $\phi_\pi > 1$. This causes output to fall but output growth is expected to rise via the dynamic IS equation (low but rising). Higher expected output growth further raises the real interest rate when $\phi_{gy} > 0$ which further lowers output and raises expected output growth, etc. The size of the multiplier for the increase in real interest rates is given by $1/(1-\phi_{gy})$. As the central bank's response to output growth approaches one, the multiplier approaches infinity. This real interest rate multiplier effect partially accounts for why strong responses to output growth help restore determinacy. Also note that similar to our results for the baseline Taylor rule with response only to inflation, making the response to inflation more aggressive does not guarantee determinacy for forward-looking rules.

Overall, our findings suggest 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

²⁰ Panel C of Appendix Figure 1 presents the same results using staggered price setting.

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.²¹

3.3 Interest Rate Smoothing

An additional extension to the basic Taylor rule which has become exceedingly common is allowing for interest smoothing as follows

$$r_t = \rho r_{t-1} + (1 - \rho) \phi_\pi E_t \pi_{t+j} \quad (5)$$

where ρ is the degree of interest smoothing. In this case, ϕ_π 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 ϕ_π be greater than one for any degree of interest smoothing between 0 and 1. Under zero trend inflation, Woodford (2003) shows that 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. Furthermore, including lagged interest rates in the reaction function makes the policy rule history-dependent which helps to anchor expectations.

We investigate the effect of introducing interest smoothing in the Taylor rule under positive trend inflation in Panel D of Figure 1.^{22,23} For both contemporaneous and forward-looking Taylor rules, higher interest smoothing makes determinacy sustainable at lower levels of ϕ_π .²⁴ 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: under positive trend inflation, interest smoothing helps achieve determinacy even conditional on the long-run response to inflation. This suggests that history-dependence is particularly useful in improving the determinacy properties of interest rate rules when $\bar{\pi} > 0$. In addition, super-inertial rules (in which $\rho \geq 1$) continue to guarantee determinacy for any positive response to the inflation rate, exactly as was the case with zero steady-state inflation. Note also that once interest rate smoothing is applied, the dramatic difference in determinacy outcomes between contemporaneous and forward-looking Taylor rules dissipates.

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

²¹ Note also that Schmitt-Grohe and Uribe (forthcoming) find that responding to output growth leads to approximately the same welfare as policies focused on the gap, conditional on the existence of a unique REE.

²² Panel D in Appendix Figure 1 presents the same results using staggered price setting.

²³ Note that for $\rho=1$, we rewrite the Taylor rule as $r_t = \rho r_{t-1} + \phi_\pi E_t \pi_{t+j}$.

²⁴ 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.

$$r_t = \phi_p dp_t$$

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 δ 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.²⁵

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 Woodford (2003) 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 δ), the smaller the long-run response to inflation will need to 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 issues 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 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. A common theme in our findings is that policy rules with more aggressive responses to inflation and an element of history-dependence are more likely to be consistent with a determinate REE. 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

²⁵ This could also be interpreted as targeting an average level of inflation. Suppose that the target for average inflation is 3% over 5 years. Then below-target inflation is later compensated with above target inflation.

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 insufficient to answer whether this rule is consistent with a determinate equilibrium.²⁶

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 Volcker disinflation and whether any such changes may have moved the economy out of an indeterminate equilibrium in the pre-Volcker 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-Volcker era was characterized by responses to inflation inconsistent with the Taylor principle but that this was not the case after the Volcker 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 then 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 measurement of the output gap. In section 4.4, we explore the correlation between volatility and trend inflation using cross-country data.

Another way to address this question would be to estimate the parameters of the Taylor rule jointly with the structural parameters of the model using full-information or Bayesian methods. This is the approach used by Lubik and Schorfheide (2004) and Boivin and Giannoni (2006).²⁷ 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

²⁶ Davig and Leeper (2007) argue that the possibility of the central banker switching to a policy rule consistent with determinacy (good policy) can lead to determinant outcomes even during times when the central banker's policy rule is not sufficiently aggressive to guarantee determinacy (bad policy). In other words, the possibility of switching to good policy mitigates the effects of bad policy. However, Davig and Leeper observe that bad policy will still lead to increased volatility of macroeconomic variables. Hence, we continue to associate indeterminacy periods with periods of increased volatility.

²⁷ Note that neither paper explicitly takes into account positive trend inflation.

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. 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-Volcker 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 beyond 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 Volcker Disinflation

As shown in section 3, determinacy in the New Keynesian model hinges on the steady state rate 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 Volcker disinflation. Our estimated Taylor rule is

$$r_t = c + (1 - \rho_1 - \rho_2)(\phi_\pi E_t \pi_{t+j} + \phi_{gy} E_t g y_{t+j} + \phi_x E_t x_{t+j}) + \rho_1 r_{t-1} + \rho_2 r_{t-2} + \varepsilon_t, \quad (6)$$

where ε_t is an error term. 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. The constant term c consists of the steady-state level of interest rate, plus the (constant) trend level of inflation and steady-state output growth. 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 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.²⁸ 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.

²⁸ We follow Orphanides and van Norden (2002) and allow for a break in the trend in 1973, but include this break in the estimation only starting in 1977.

Note that, as Orphanides (2001, 2004), Boivin (2006) and others argue, 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 on 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.²⁹

Table 1 present 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 is 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.³⁰ We also include the probability value of the null that each of the parameters and the sum of interest smoothing parameters are the same in the two periods. We find that the Fed's response to inflation in the pre-Volcker 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 Volcker 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

²⁹ We are thus implicitly assuming constant trend inflation, constant target GDP growth, and a constant natural rate within each time sample. Results in Kozicki and Tinsley (2007) suggest that this is a reasonable approximation within each subsample.

³⁰ 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.

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 Volcker disinflation was characterized by a strong long-run response to the output gap, but no apparent response to output growth, the period since the Volcker 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 Volcker 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 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 ($\lambda=0.55$). 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.³¹ 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 1.³²

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

³¹ The estimates of 6% and 3% trend inflation rate before and after Volcker are consistent with Kozicki and Tinsley (2007), Cogley and Sargent (2005) and others who use structural models to infer the unobserved target level of inflation.

³² 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 30.

distribution of parameters yields determinacy. Thus, like Taylor (1999), Clarida et al (2000) and others, we find that monetary policy before Volcker 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 Volcker 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 Volcker disinflation, it is quite possible that the US economy would have remained subject to self-fulfilling expectations-driven 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 Volcker 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 Volcker 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 address the quantitative importance of 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.³³ We continue to use Calvo price setting with average price duration halfway between Bils and Klenow (2004) and Nakamura and Steinsson (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 Volcker disinflation* can account for much of the movement away from indeterminacy. Specifically, we find that if the Fed had maintained its pre-Volcker policy rule but used the post-1982 inflation response, then this single policy switch combined with the Volcker 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 Volcker 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 Volcker 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 Volcker, then the likelihood that the US economy would still be in the indeterminacy region would be much higher. We find that 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

³³ 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. We assume a once and for all unexpected change in the parameters of the policy rule even though a more realistic description of policy changes would involve gradual transitions in parameter values (see Boivin 2006).

supports the emphasis placed by Orphanides (2004) on the lower response to the output gap by the Fed since the Volcker 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, achieved via the Volcker 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.³⁴ 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.

³⁴ Here, we draw from each period's distribution of parameters, then impose that the relevant coefficient be exactly zero for each draw.

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 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 degrees 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 $\lambda=0.40$. Second, we follow Nakamura and Steinsson (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 $\lambda=0.70$. 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-Volcker policy was generally inconsistent with determinacy at a 6% inflation rate.³⁵ 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 Steinsson moves all of the quantitative results in the opposite direction. For the pre-Volcker 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.³⁶ 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

³⁵ The latter is particularly important since one might expect that prices were changed more frequently in the 1970s due to the higher trend inflation. Our indeterminacy results in the pre-Volcker era thus hold for higher price-changing frequencies than assumed in the baseline. Unfortunately, there is little direct evidence of how frequently prices changed in the 1970s.

³⁶ Another way to see this limitation of the Calvo model is to note that using Nakamura and Steinsson rates of price-setting, the Calvo model breaks down at an inflation rate of 6.1%.

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-Volcker 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 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 setting a lower bound on determinacy issues (conditional on average price durations) and Calvo pricing 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-Volcker 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 Steinsson (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 ω , 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:

$$\begin{aligned}\gamma_1^* &= \gamma_1 \bar{\Pi}^{\omega(1-\theta)} \\ \gamma_2^* &= \gamma_2 \bar{\Pi}^{-\omega\theta(1+\eta^{-1})}.\end{aligned}$$

and the relationship between the reset price and inflation is now given by

$$\pi_t = \left(\frac{1 - \lambda \bar{\Pi}^{(1-\omega)(\theta-1)}}{\lambda \bar{\Pi}^{(1-\omega)(\theta-1)}} \right) b_t.$$

In the special case of full-indexation ($\omega = 1$), then $\gamma_1^* = \gamma_2^*$ and the supply-side collapses to the standard NKPC.³⁷

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 5.³⁸ Figure 5 makes clear that as indexation rises, the fraction of the empirical distribution of Taylor rule estimates consistent with determinacy also 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-Volcker 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.³⁹ 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 (e.g., Fuhrer (2000)). To consider the implications of habit formation for our results, we replace the consumer's objective function with the following

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

where the consumer treats the stock of habit H_t as exogenously determined ("external" habit) but it is actually 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 previous section using baseline parameters and habit formation in Table 3. The results are almost identical to our baseline case.

³⁷ 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.

³⁸ We continue to assume $\lambda=0.55$, 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).

³⁹ This is why, for each time period, the 3% and 6% lines converge to the same value when $\omega = 1$.

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.

4.4 International aspect of the Great Moderation

The decline in volatility of economic activity has been observed not only in the US but also in many other countries. However, the timing of the decline varies across countries thus suggesting the Great Moderation was probably not driven by global shocks. We argue that the Great Moderation in the US is consistent with improvements in monetary policy which includes both changes in the policy reaction function and significant decreases in the level of inflation. One might expect that similar forces could account for the declining GDP volatility in other countries as well. Since we do not have real time data and forecasts for other countries, we can examine only whether macroeconomic volatility fell when countries moved to lower trend inflation rates.

Following Blanchard and Simon (2001), we compute σ_{it} , the volatility of real GDP growth rates $gy_{it} = \log(GDP_{it}/GDP_{i,t-1}) \times 100$ for country i and time t , over t to $t - 20$ quarters. We use the same window to compute the average inflation rate $\bar{\pi}_{it}$, which approximates the trend inflation rate and where the inflation rate in period t for country i is $\pi_{it} = \log(CPI_{it}/CPI_{i,t-1}) \times 400$.⁴⁰ The mean values for σ_{it} and $\bar{\pi}_{it}$ are 0.95 and 5.35 respectively. Figure 3 plots the time series of σ_{it} and $\bar{\pi}_{it}$ for a set of developed countries.

We observe strong comovement in trend inflation and volatility with a few exceptions. Periods of low trend inflation tend to coincide with period of low macroeconomic volatility. The unconditional correlation between $\bar{\pi}_{it}$

⁴⁰ Real GDP growth rates and inflation rates are seasonally adjusted. The sources of the data are Quarterly National Accounts from OECD and International Financial Statistics from IMF.

and σ_{it} is high at 0.49 when we use cross-country data and stunning at 0.81 when we use US data only. To formally assess the strength of the comovement, we estimate the following specification:

$$\sigma_{it} = \alpha \bar{\pi}_{it} + \lambda_i + \mu_t + u_{it}, \quad (7)$$

where λ_i and μ_t are country and period fixed effects and u_{it} is the error term. Note that in the specification with time specific effects we control for global shocks (e.g., changes in commodity prices) for each quarter in our data. We also consider a specification in which time fixed effects are replaced with polynomials in time. Estimates of α (Table 4) suggest an economically and statistically significant relationship between trend inflation and volatility. In particular, a one-standard-deviation increase in inflation, which is equal to 4.19, is associated with 0.13 to 0.2 increase in volatility σ_{it} , which approximately corresponds to a 14-22% increase in volatility relative to the mean volatility.

Given our arguments for the USA, we interpret these findings as suggestive evidence that the Great Moderation across countries was in part determined by reductions in trend inflation. These lower levels of trend inflation contributed to making monetary policy more effective at stabilizing economic activity. In a sense, one may associate the end of the Great Inflation with the beginning of the Great Moderation.⁴¹ Cross-country evidence also suggests that the cost of trend inflation may have been understated in previous studies since the link between positive trend inflation and macroeconomic volatility has not been explored.

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 Volcker's accession as chairman of the Fed as a primary source of economic stabilization. Building on recent work by Ascari 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-Volcker 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

⁴¹ Although some researchers link the increased trend inflation with indeterminacy, we are agnostic about sources of changes in the trend inflation which could have started also due to mis-measurement of potential output or using the wrong model for policy. We take the changes in trend inflation as exogenous in our analyses.

changes that we emphasize differ from the consensus monetary policy interpretation. One novel finding is that the Volcker 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. In a similar vein, we find that decreased levels of inflation were associated with decreased macroeconomic volatility in other countries. 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 (2007), 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 Volcker 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 Volcker 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 period of high economic volatility could still occur.

References

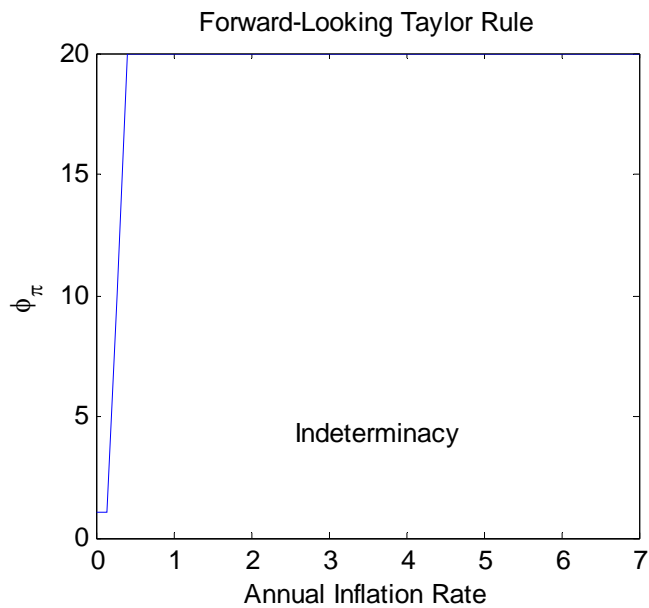
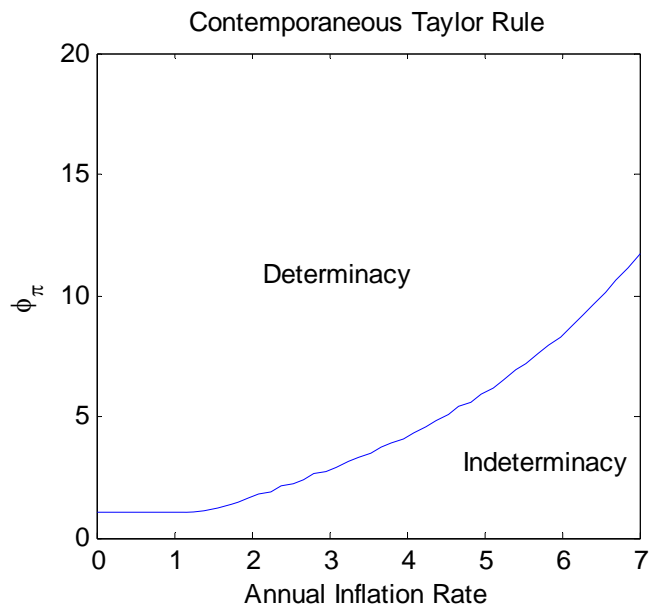
- Ascari, Guido and Tiziano Ropele, 2007, "Trend Inflation, Taylor Principle, and Indeterminacy," manuscript.
- Bakhshi, Hasan, Hashmat Khan, Pablo Burriel-Llombart, and Barbara Rudolf, 2007, "The New Keynesian Phillips Curve under Trend Inflation and Strategic Complementarity," *Journal of Macroeconomics*, 29(2007), 37-59.
- Bils, Mark and Peter J. Klenow, 2004, "Some Evidence on the Importance of Sticky Prices," *Journal of Political Economy*, 112(5), 947-985.
- Blanchard, Olivier and John Simon, 2001, "The Long and Large Decline in U.S. Output Volatility," *Brookings Papers on Economic Activity*, 1(2001), 135-164.
- Blinder, Alan S. and Ricardo Reis, 2005, "Understanding the Greenspan Standard," In: The Greenspan Era: Lessons for the Future, Jackson Hole: Federal Reserve Bank of Kansas City, 11-96.

- Boivin, Jean and Marc Giannoni, 2006, "Has Monetary Policy Become More Effective?" *Review of Economics and Statistics*, 88(3), 445-462.
- Boivin, Jean, 2006, "Has U.S. Monetary Policy Changed? Evidence from Drifting Coefficients and Real-Time Data," *Journal of Money, Credit and Banking* 38(5), 1149-1173.
- Bullard, James and Stefano Eusepi, 2005, "Did the Great Inflation Occur despite Policymaker Commitment to a Taylor Rule?" *Review of Economic Dynamics*, 8(2005), 324-359.
- Bullard, James and Kaushik Mitra, 2002, "Learning about Monetary Policy Rules," *Journal of Monetary Economics* 49, 1105-1129.
- Calvo, Guillermo, 1983, "Staggered Prices in a Utility-Maximizing Framework," *Journal of Monetary Economics*, 12(3), 383-98.
- Christiano, Lawrence, Martin Eichenbaum, and Charles Evans, 2005, "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," *Journal of Political Economy*, 113(1), 1-45.
- Clarida, Richard, Jordi Galí, and Mark Gertler, 2000, "Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory," *Quarterly Journal of Economics*, 115(1), 147-180.
- Clarida, Richard, Jordi Galí, and Mark Gertler, 1999, "The science of monetary policy: A new keynesian perspective," *Journal of Economic Literature*, 37(4), 1661-1707.
- Cogley, Timothy and Argia Sbordone, "Trend Inflation, Indexation and Inflation Persistence in the New Keynesian Phillips Curve," forthcoming in *American Economic Review*.
- Cogley, Timothy, Giorgio E. Primiceri, and Thomas J. Sargent, 2008, "Inflation-Gap Persistence in the U.S." manuscript.
- Cogley, Timothy, and Thomas J. Sargent, 2005, "Drifts and Volatilities: Monetary Policies and Outcomes in the Post WWII US," *Review of Economic Dynamics* 8(2), 262-302.
- Davig, Troy and Eric M. Leeper, 2007, "Generalizing the Taylor Principle," *American Economic Review* 97(3), 607-635.
- Fuhrer, Jeffrey C., 2000, "Habit Formation in Consumption and Its Implications for Monetary-Policy Models," *American Economic Review*, 90(3), 367-390.
- Gorodnichenko, Yuriy and Matthew D. Shapiro, 2007, "Monetary policy when potential output is uncertain: Understanding the growth gamble of the 1990s," *Journal of Monetary Economics*, 54(4), 1132-1162.
- Hornstein Andreas and Alexander L. Wolman, 2005, "Trend Inflation, Firm-Specific Capital, and Sticky Prices," Federal Reserve Bank of Richmond *Economic Quarterly*, 91(4), 57-83.
- Ireland, Peter. 2004. "Technology Shocks in the New Keynesian Model," *Review of Economics and Statistics* 86(4), 923-936.
- Ireland, Peter, 2007, "Changes in the Federal Reserve's Inflation Target: Causes and Consequences," forthcoming in *Journal of Money, Credit, and Banking*.
- Justiniano, Alejandro and Giorgio E. Primiceri, "The Time-Varying Volatility of Macroeconomic Fluctuations," forthcoming *American Economic Review*.
- Kahn, James A., Margaret M. McConnell, and Gabriel Perez-Quirós, 2002, "On the Causes of the Increased Stability of the U.S. Economy," *Economic Policy Review* of the Federal Reserve Bank of New York, 8(1), 183-206.
- Kiley, Michael E., 2007, "Is Moderate-to-High Inflation Inherently Unstable?" *International Journal of Central Banking*, 3(2), 173-201.
- Kozicki, Sharon and P.A. Tinsley, 2007, "Perhaps the FOMC Did What It Said It Did: An Alternative Interpretation of the Great Inflation," Bank of Canada Working Paper 2007-19.
- Lubik, Thomas A. and Frank Schorfheide, 2004, "Testing for Indeterminacy: An Application to U.S. Monetary Policy," *American Economic Review*, 94(1), 190-217.
- Nakamura, Emi and Jón Steinsson, "Five Facts About Prices: A Reevaluation of Menu Cost Models," forthcoming in *Quarterly Journal of Economics*.
- Orphanides, Athanasios, 2001, "Monetary Policy Rules Based on Real-Time Data," *American Economic Review*, 91(4), 964-985.
- Orphanides, Athanasios, 2002, "Monetary Policy Rules and the Great Inflation," *American Economic Review, Papers and Proceedings*, 92(2), 115-120.

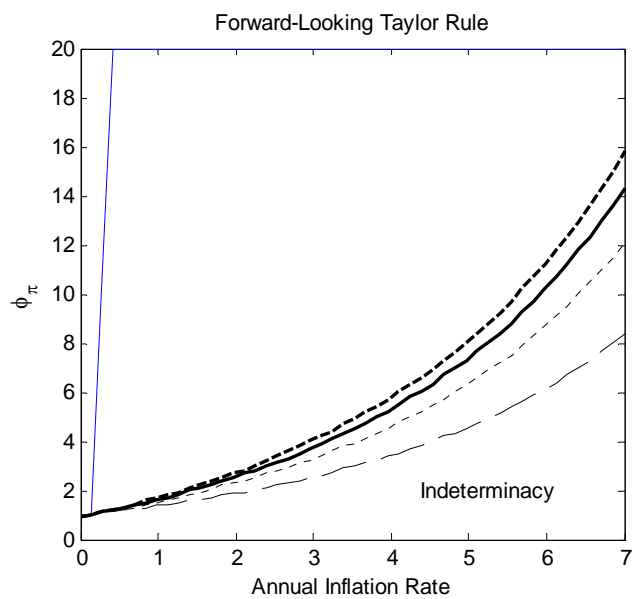
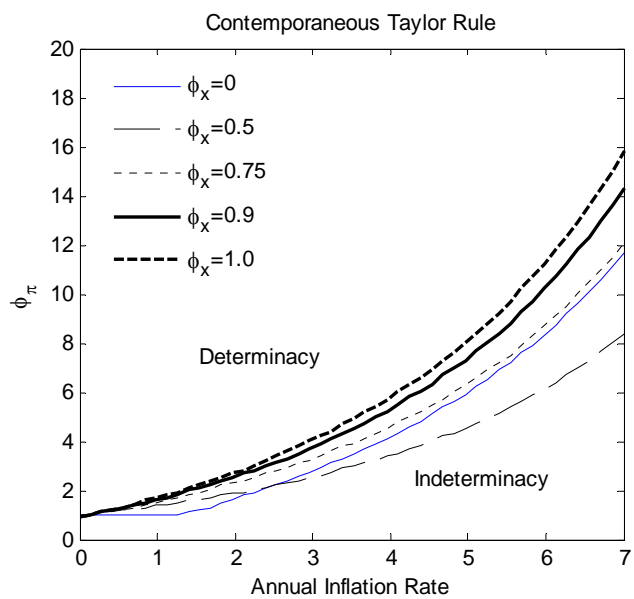
- Orphanides, Athanasios, 2003, "Historical Monetary Policy Analysis and the Taylor Rule," *Journal of Monetary Economics*, 50(5), 983-1022.
- Orphanides, Athanasios, 2004, "Monetary Policy Rules, Macroeconomic Stability and Inflation: A View from the Trenches," *Journal of Money, Credit, and Banking* 36(2), 151-175.
- Orphanides, Athanasios and Simon van Norden, 2002, "The Unreliability of Output Gap Estimates in Real Time," *Review of Economics and Statistics*, 84(4), 569-583.
- Orphanides, Athanasios and John C. Williams, 2006, "Monetary policy with imperfect knowledge," *Journal of the European Economic Association*, 4(2-3), 366-375.
- Primiceri, Giorgio E., 2006, "Why Inflation Rose and Fell: Policymakers' Beliefs and US Postwar Stabilization Policy," *Quarterly Journal of Economics*, 121, 867-901.
- Romer, Christina H. and David H. Romer, 2004, "A New Measure of Monetary Shocks: Derivation and Implications," *American Economic Review*, 94 (September 2004), 1055-1084.
- Sargent, Thomas J., 1999, The Conquest of American Inflation, Princeton University Press, Princeton N.J.
- Schmitt-Grohé, Stephanie and Martin Uribe, "Optimal Simple and Implementable Monetary and Fiscal Rules," forthcoming in *Journal of Monetary Economics*.
- Sims, Christopher A. and Tao Zha, 2006, "Were There Regime Switches in U.S. Monetary Policy?" *American Economic Review*, 96(1), 54-81.
- Svein, Tommy and Lutz Weinke, 2005, "New perspectives on capital, sticky prices, and the Taylor principle," *Journal of Economic Theory*, 123(2005), 21-39.
- Taylor, John B., 1977, "Staggered Wage Setting in a Macro Model," *American Economic Review Papers and Proceedings*, 69(2), 108-113.
- Taylor, John B., 1999, "An Historical Analysis of Monetary Policy Rules," in John B. Taylor (ed.) Monetary Policy Rules, University of Chicago Press.
- Walsh, Carl E., 2003, "Speed Limit Policies: The Output Gap and Optimal Monetary Policies," *American Economic Review*, 93(1), 265-278.
- Woodford, Michael, 2003, Interest and Prices: Foundations of a Theory of Monetary Policy, Princeton: Princeton University Press.
- Yun, Tack, 1996, "Nominal Price Rigidity, Money Supply Endogeneity, and Business Cycles," *Journal of Monetary Economics*, vol. 37 (April 1996), 345-370.

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

Panel A: Basic Taylor Rules

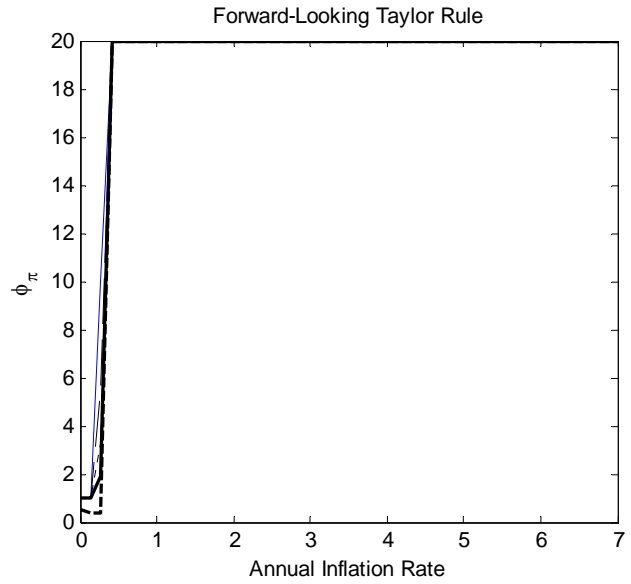
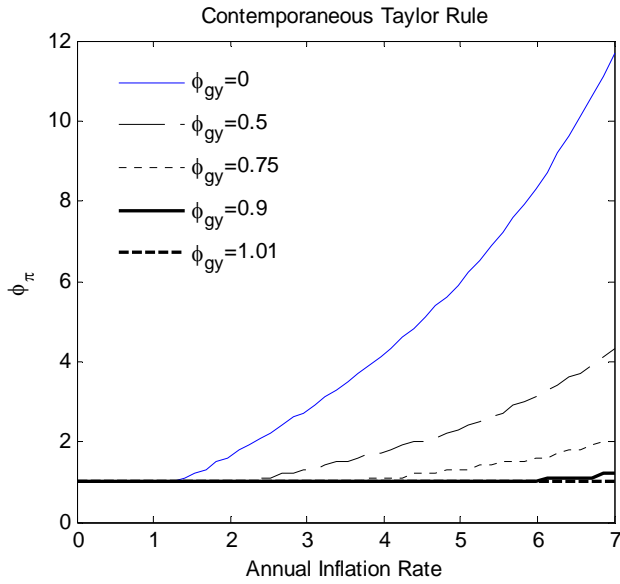


Panel B: Responding to Output Gap

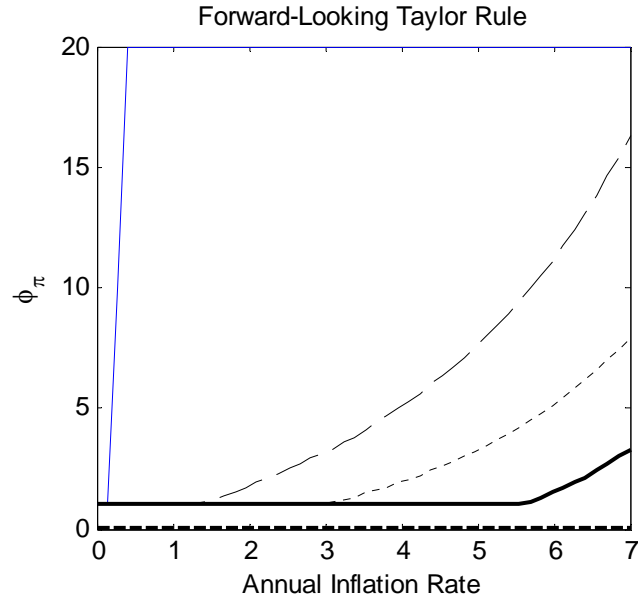
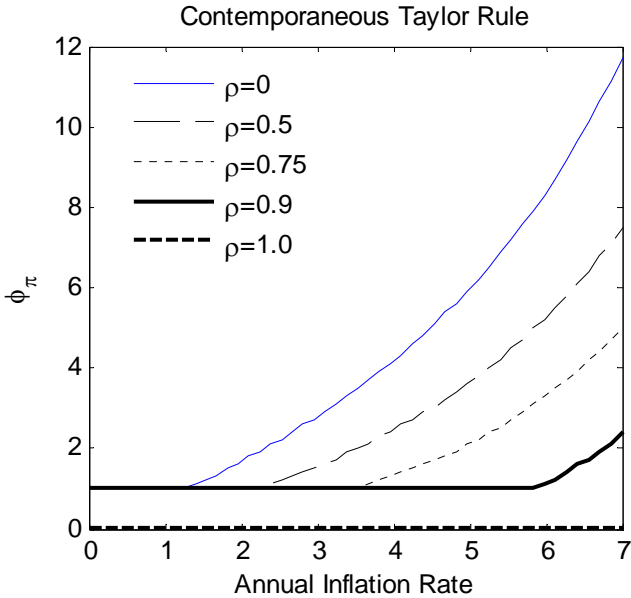


(continued on next page)

Panel C: Responding to Output Growth

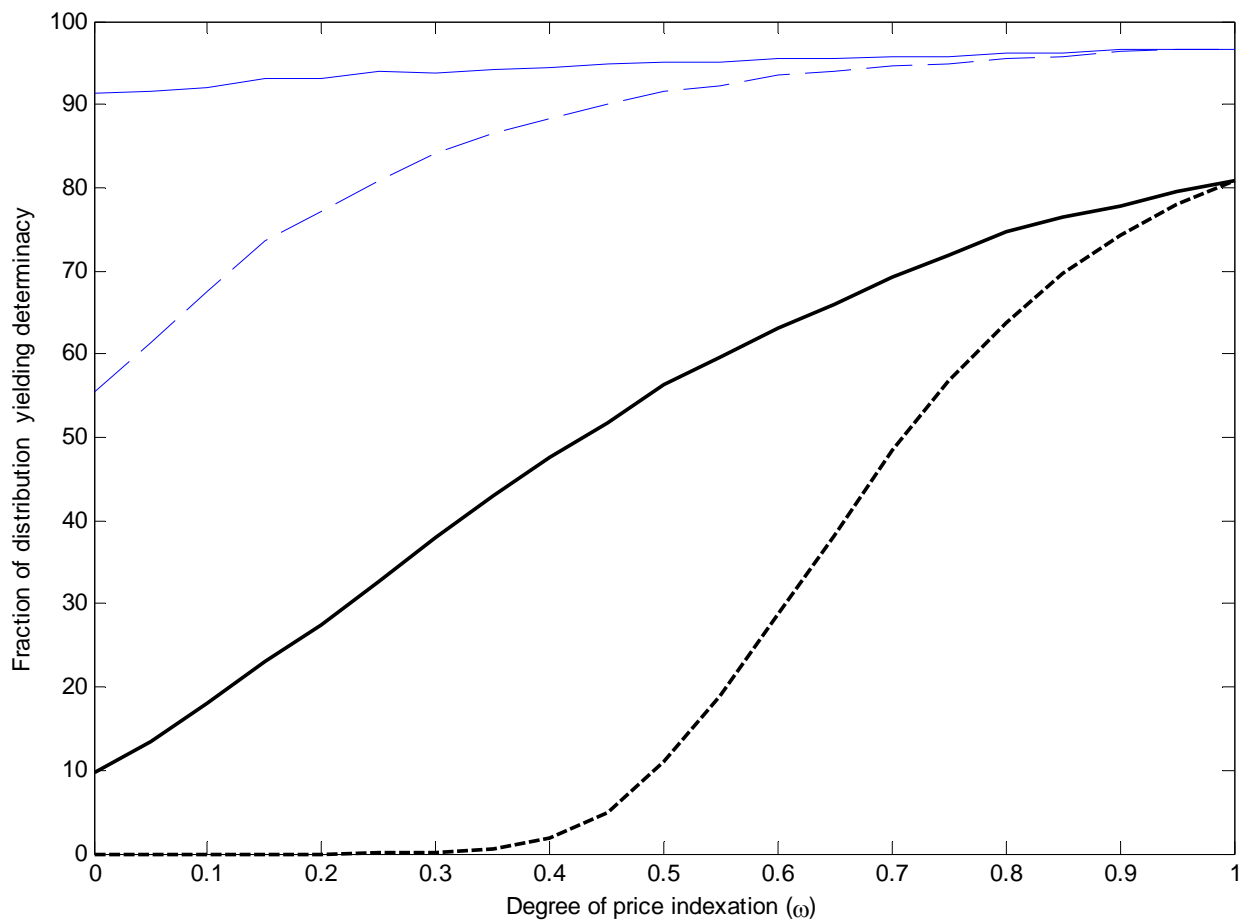


Panel D: Interest Smoothing



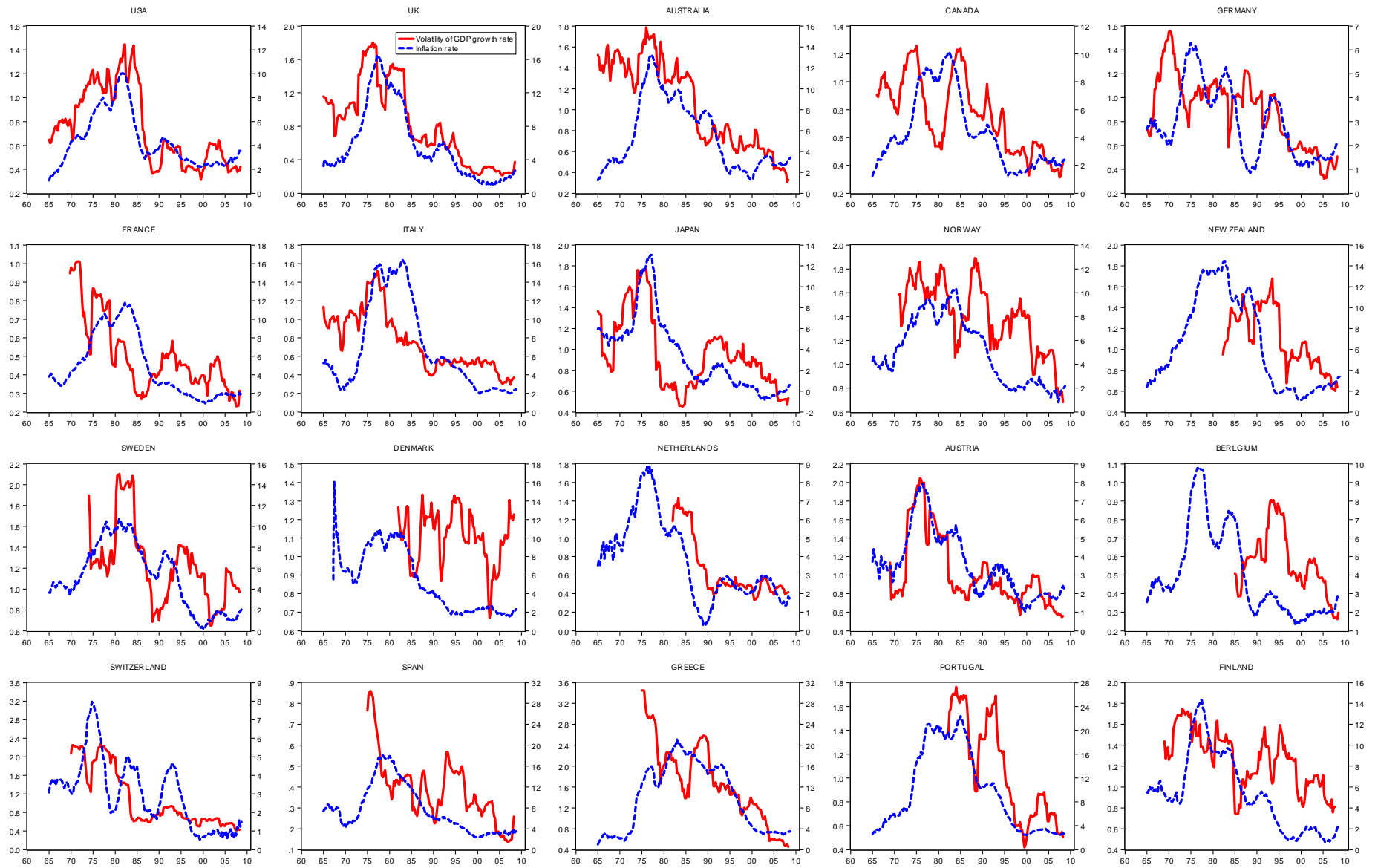
Notes: Steady-state inflation rate is on horizontal axis. The response to inflation in the Taylor rule is on vertical axis. The basic Taylor rule has zero response to output gap and output growth rate as well as no interest rate smoothing. Forward rules respond to expected values of macroeconomic variables ($j = 1$) while the contemporaneous rules respond to current values of macroeconomic variables ($j = 0$). The model and calibration of parameter is described in the text. Panel A: The basic Taylor rule has zero response to output gap and output growth rate as well as no interest rate smoothing, i.e. $r_t = \phi_\pi E_t \pi_{t+j}$ where π_t is the inflation rate. Panel B: The simulated policy rule is $r_t = \phi_\pi E_t \pi_{t+j} + \phi_x E_t x_{t+j}$ where x_t is output gap. Panel C: The simulated policy rule is $r_t = \phi_\pi E_t \pi_{t+j} + \phi_{gy} E_t gy_{t+j}$ where gy_t is the growth rate of output. Panel D: $r_t = \rho r_{t-1} + (1 - \rho) \phi_\pi E_t \pi_{t+j}$ where ρ is the degree of interest smoothing. For $\rho = 1$, the simulated Taylor rule is $r_t = \rho r_{t-1} + \phi_\pi E_t \pi_{t+j}$.

Figure 2: 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. The model and calibration of parameter is described in the text.

Figure 3: Trend inflation and volatility of real GDP growth rates across countries.



Note: The blue dashed line is average annualized CPI inflation over current and past 20 quarters. The red solid line is the volatility of real GDP growth over current and past 20 quarters.

Table 1: Reduced Form Estimates of Taylor Rule

	Contemporaneous Taylor Rule			Forward-Looking Taylor Rule			Mixed Taylor Rule		
	pre 1979	post 1982	p-val equality of response	pre 1979	post 1982	p-val equality of response	pre 1979	post 1982	p-val equality of response
$\phi_{t,\pi}$	0.80*** (0.23)	1.19*** (0.41)	0.42						
$\phi_{f,\pi}$				1.44** (0.57)	1.83*** (0.54)	0.61	1.25*** (0.31)	1.68*** (0.38)	0.37
$\phi_{t,gy}$	-0.02 (0.10)	1.91** (0.82)	0.02				-0.18* (0.10)	1.29*** (0.37)	0.00
$\phi_{f,gy}$				0.01 (0.36)	1.62** (0.77)	0.05			
$\phi_{t,x}$	0.55*** (0.12)	0.14 (0.17)	0.06						
$\phi_{f,x}$				0.85** (0.33)	0.23 (0.16)	0.09	0.74*** (0.18)	0.24** (0.11)	0.02
ρ_1	1.38*** (0.09)	1.16*** (0.09)		1.29*** (0.09)	1.33*** (0.09)		1.30*** (0.09)	1.11*** (0.10)	
ρ_2	-0.50*** (0.09)	-0.22** (0.10)		-0.37*** (0.09)	-0.39*** (0.09)		-0.41*** (0.10)	-0.20* (0.10)	
R^2	0.97	0.98		0.97	0.98		0.97	0.98	
s.e.e.	0.40	0.29		0.40	0.31		0.40	0.29	
$\rho_1 + \rho_2$	0.56	0.89	0.00	0.72	0.86	0.14	0.62	0.84	0.01
<i>Determinacy</i>									
<i>3% inflation</i>	No	Yes		No	Yes		No	Yes	
<i>Fraction at 3%</i>	0.2%	58.3%		30.2%	87.3%		9.5%	91.3%	
<i>6% inflation</i>	No	No		No	Yes		No	Yes	
<i>Fraction at 6%</i>	0.0%	35.7%		0.9%	62.4%		0.0%	54.6%	

Notes: 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. $\phi_{f,*}$ corresponds to the average forecast of the next 2 quarters in Taylor rule estimated in equation (6). $\phi_{t,*}$ 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

	Taylor rule parameters					Steady state inflation	
	ϕ_{π}	ϕ_{gy}	ϕ_x	ρ_1	ρ_2	3%	6%
Pre-1979 period							
Baseline Taylor Rule Estimates	1.25	-0.18	0.74	1.30	-0.41	9.5%	0.0%
Switch Inflation Response	1.68	-0.18	0.74	1.30	-0.41	65.9%	0.0%
Switch Interest Smoothing Parameters	1.25	-0.18	0.74	1.11	-0.20	10.1%	0.0%
Switch Output Growth Response	1.25	1.29	0.74	1.30	-0.41	10.2%	0.0%
Switch Output Gap Response	1.25	-0.18	0.24	1.30	-0.41	22.1%	0.0%
Zero Output Gap Response	1.25	-0.18	0	1.30	-0.41	2.9%	0.0%
Zero Output Gap and Output Growth Response	1.25	0	0	1.30	-0.41	5.1%	0.0%
Post-1982 period							
Baseline Taylor Rule Estimates	1.68	1.29	0.24	1.11	-0.20	91.3%	54.6%
Switch Inflation Response	1.25	1.29	0.24	1.11	-0.20	57.6%	18.4%
Switch Interest Smoothing Parameters	1.68	1.29	0.24	1.30	-0.41	90.9%	54.3%
Switch Output Growth Response	1.68	-0.18	0.24	1.11	-0.20	76.3%	15.0%
Switch Output Gap Response	1.68	1.29	0.74	1.11	-0.20	63.2%	20.0%
Zero Output Gap Response	1.68	1.29	0	1.11	-0.20	96.2%	92.2%
Zero Output Gap and Output Growth Response	1.68	0	0	1.11	-0.20	87.9%	8.4%

Notes: 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

	Pre-1979 period		Post-1982 period	
	Determinacy at point estimates	Fraction of determinate equilibria given sampling uncertainty	Determinacy at point estimates	Fraction of determinate equilibria given sampling uncertainty
Bils and Klenow Case (change prices every 5 months)				
<i>3% inflation</i>	Yes	56.5%	Yes	95.3%
<i>6% inflation</i>	No	7.4%	Yes	91.4%
Nakamura and Steinson Case (change prices every 10 months)				
<i>3% inflation</i>	No	0.0%	No	46.7%
<i>6% inflation</i>	No	0.0%	No	2.0%
Taylor Staggered Price Setting (duration of 9 months)				
<i>3% inflation</i>	Yes	57.3%	Yes	95.0%
<i>6% inflation</i>	No	16.9%	Yes	93.3%
Baseline with habit formation ($h = .9$)				
<i>3% inflation</i>	No	10.0%	Yes	91.7%
<i>6% inflation</i>	No	0.0%	Yes	56.3%
Alternative Measure of Real-Time Output Gap (quadratic trend)				
<i>3% inflation</i>	No	0.4%	Yes	95.3%
<i>6% inflation</i>	No	0.1%	No	23.6%
Taylor rules with price level targeting				
<i>3% inflation</i>	No	14.3%	Yes	93.8%
<i>6% inflation</i>	No	0.2%	Yes	53.9%

Notes: 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.

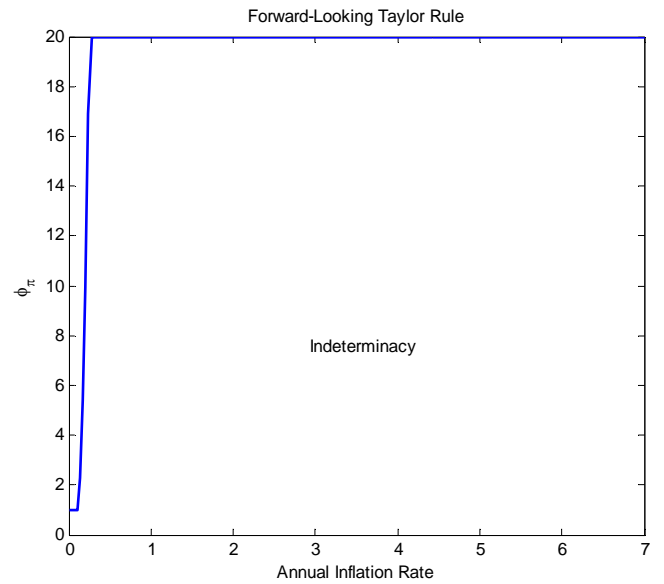
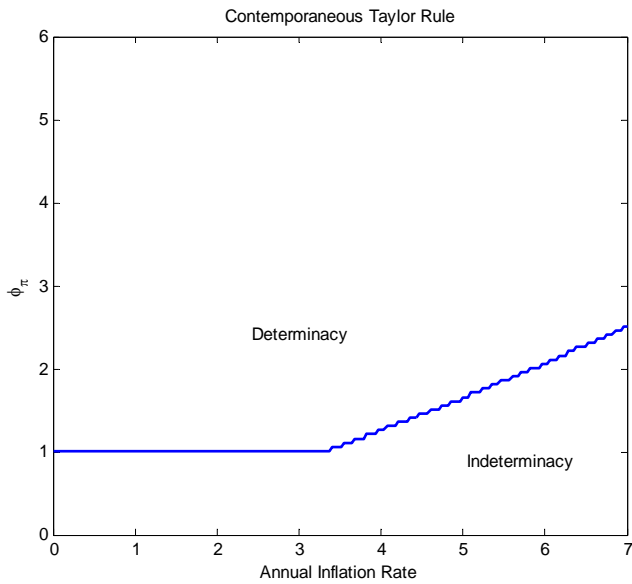
Table 4. Macroeconomic volatility and trend inflation across countries

	Dependent variable: Volatility of real GDP			
	growth rate σ_{it}			
	(1)	(2)	(3)	(4)
Trend inflation $\bar{\pi}_{it}$	0.052*** (0.010)	0.056*** (0.006)	0.029** (0.012)	0.031*** (0.008)
Country fixed effect	N	Y	Y	Y
Time fixed effect	N	N	Y	N
Time polynomials	N	N	N	Y
Observations	2,886	2,886	2,886	2,886
R-squared	0.261	0.666	0.764	0.745

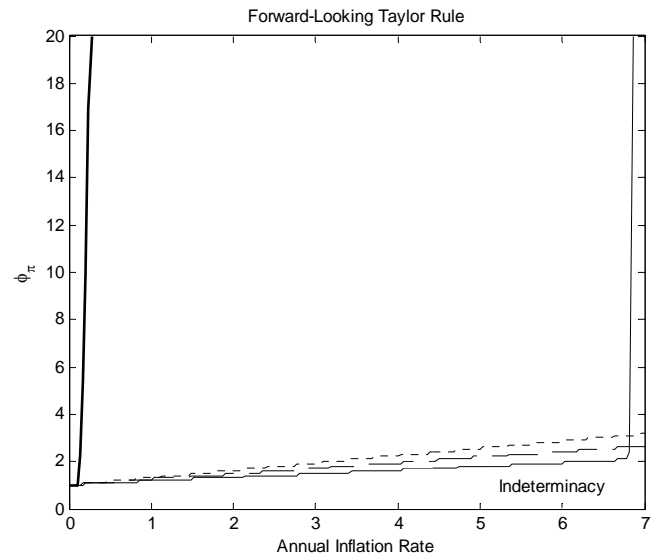
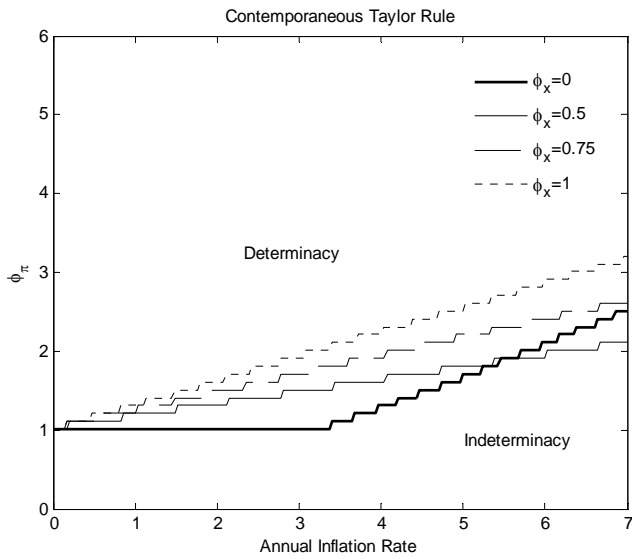
Notes: The table reports estimates for equation (7). Robust standard errors are reported in parentheses. Standard errors are clustered by country to allow for arbitrary serial correlation. *, **, *** indicates statistical significance at the 10%, 5%, and 1% level respectively. Time polynomials include linear and quadratic time trends.

Appendix Figure 1: Determinacy in a New Keynesian Model with Taylor Staggered Pricing for Positive SS Inflation Rates:

Panel A: Basic Taylor Rules

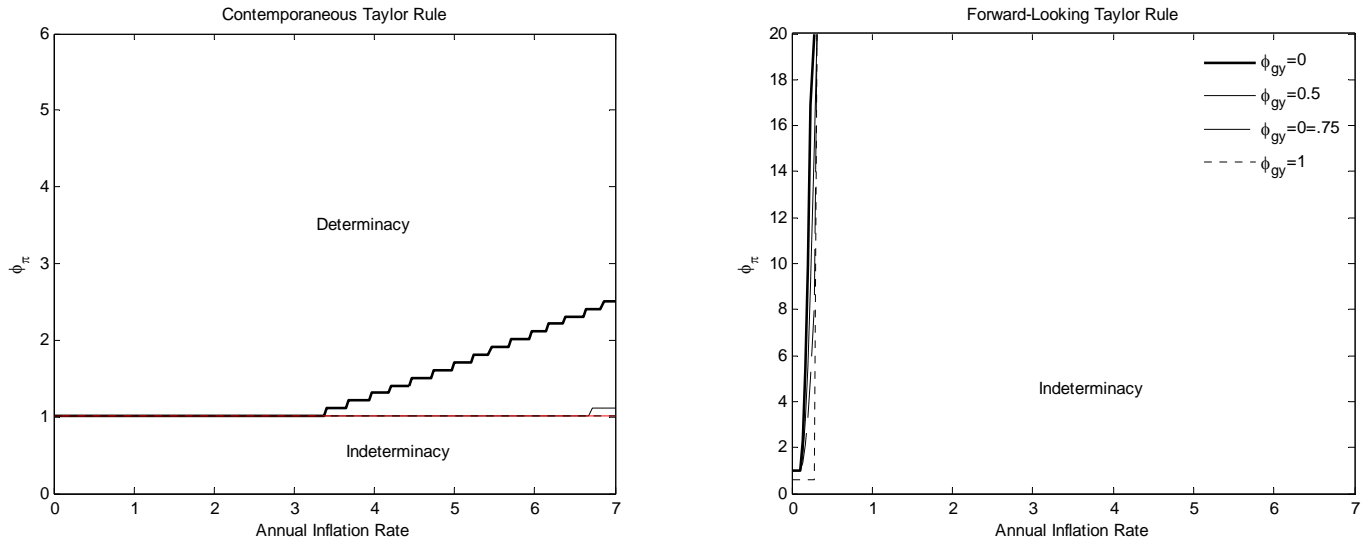


Panel B: Responding to Output Gap

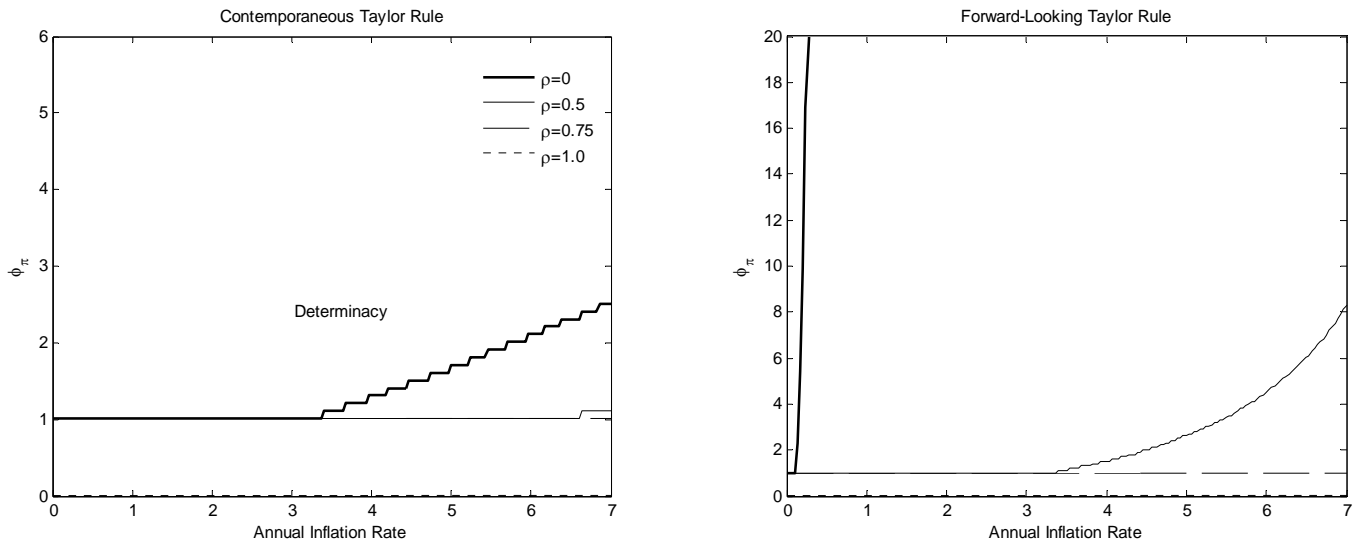


(continued on next page)

Panel C: Responding to Output Growth



Panel D: Interest Smoothing



Notes: 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. Forward rules respond to expected values of macroeconomic variables ($j = 1$) while the contemporaneous rules respond to current values of macroeconomic variables ($j = 0$). The model and calibration of parameter is described in the text. Panel A: The basic Taylor rule has zero response to output gap and output growth rate as well as no interest rate smoothing, i.e. $r_t = \phi_\pi E_t \pi_{t+j}$ where π_t is the inflation rate. Panel B: The simulated policy rule is $r_t = \phi_\pi E_t (\pi_{t+j} + \phi_x E_t x_{t+j})$ where x_t is output gap. Panel C: The simulated policy rule is $r_t = \phi_\pi E_t \pi_{t+j} + \phi_{gy} E_t gy_{t+j}$ where gy_t is the growth rate of output. Panel D: $r_t = \rho r_{t-1} + (1 - \rho) \phi_\pi E_t \pi_{t+j}$ where ρ is the degree of interest smoothing. For $\rho = 1$, the simulated Taylor rule is $r_t = \rho r_{t-1} + \phi_\pi E_t \pi_{t+j}$. In all simulations the duration of price contract is three quarters.