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Monetary Policy, Trend Inflation and the Great Moderation: An Alternative Interpretation – Comment.*

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Abstract

Working with a small-scale calibrated New-Keynesian model, Coibion and Gorodnichenko (2011) find that the reduction in trend inflation during Volcker's mandate was a key factor behind the Great Moderation. We revisit this finding with an estimated New-Keynesian model with trend inflation and no indexation based on Christiano, Eichenbaum and Evans (2005). First, our simulations confirm Coibion and Gorodnichenko's (2011) main finding. Second, we show that a trend inflation-immune Taylor rule based on economic theory can avoid indeterminacy even at high levels of trend inflation such as those observed in the 1970s.

JEL: E52, E3, C22. **Keywords**: Trend Inflation, Determinacy, and Monetary Policy.

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1 Introduction

Coibion and Gorodnichenko (2011) argue that trend inflation was a key factor behind the Great Moderation. Working with a calibrated small-scale New-Keynesian model, they show that the U.S. economy switched to determinacy not only as a result of a change in the Federal Reserve's response to macroeconomic variables, but also due to the substantial reduction in the level of trend inflation during Volcker's mandate. This finding calls for caution in evaluating arguments in favor of raising the inflation target. Blanchard, Dell'Ariccia and Mauro (2010), Krugman (2013), and Ball (2014) have recently suggested considering a higher inflation target around 4 percent to provide the Federal Reserve with more room to influence real interest rates when facing large negative shocks. In light of Coibion and Gorodnichenko's (2011) findings, a higher inflation target could induce a return to indeterminacy, and hence a return to the volatility of the 1970s. Should the proposals of a higher inflation target be dismissed based on this risk?

Given the influence that Coibion and Gorodnichenko (2011) could have in answering this question, we assess their main results by employing an operational estimated medium-scale New-Keynesian model. In particular, we modify the medium-scale New-Keynesian model developed by Christiano, Eichenbaum and Evans (2005) to embed positive trend inflation without indexation, and then we estimate it with Bayesian techniques to match the same set of observables as Smets and Wouters (2007). Importantly, our empirical exercise allows for indeterminacy by following Lubik and Schorfheide (2004) so that our posterior draws are not restricted to parameters consistent with determinacy. In addition, inspired by the discussion on raising the inflation target we use well known properties of the systematic component of monetary policy as well as new analytical insights to design a monetary policy rule that can implement a 4 percent inflation target without falling into indeterminacy.

This comment presents two contributions to the literature. First, it shows that trend inflation affects the determinacy properties in a medium-sized estimated model. We combine the posterior mean of our estimated model with the Taylor rule parameters estimated by Coibion and Gorodnichenko (2011) and we replicate their policy counterfactuals. The results confirm that the reduction in the level of trend inflation has been a key factor behind the Great Moderation as argued by Coibion and Gorodnichenko (2011). Second, it proposes an empirically plausible and theoretically grounded monetary policy rule, which we refer to as a trend inflation immune Taylor rule (TIIT). Conditional on the policy counterfactuals mentioned above, the TIIT rule delivers determinacy even when trend inflation is as high as in the 1970s. Hence, our findings suggest that a 4 percent inflation target can be implemented without necessarily driving the U.S. economy to indeterminacy as long as the correct responses to the output gap and output growth are engineered.

The TIIT rule is motivated by the work of Kiley (2007), Ascari and Ropele (2009), and Coibion and Gorodnichenko (2011), among others, who underscore the relevance of the systematic component of monetary policy in anchoring inflation expectations.[1] The proposed rule features an aggressive response to inflation, a high degree of interest rate smoothing, a zero response to the output gap, and a strong response to output growth. The first two features come from our estimation and are consistent with the literature. The third feature follows directly from Ascari and Ropele (2009), who show the destabilizing role of responding to the output gap. The fourth feature has been documented by Coibion and Gorodnichenko (2011) and it is motivated by the fact that history dependence helps anchoring inflation expectations and thus shields the economy against indeterminacy. As for this last feature, we derive a novel analytical result and we use it as a foundation to find a threshold for the response to output growth above which indeterminacy is avoided even in the presence of trend inflation.

The rest of our comment is structured as follows. Section 2 briefly describes the model and the estimation methodology. Section 3 replicates Coibion and Gorodnichenko's (2011) main counterfactual simulations with our estimated model. Section 4 shows that there exists a reasonable Taylor rule that prevents the economy from falling into indeterminacy even in the presence of trend inflation levels like those observed in the 1970s. Section 5 provides intuition on why the TIIT rule ensures determinacy. Section 6 concludes.

2 Methodology

2.1 An estimated New-Keynesian model with trend inflation

We modify Christiano, Eichenbaum and Evans's (2005) framework by allowing trend inflation to affect the steady state and the dynamics of the economy. Since the model has been extensively analyzed in the literature, we briefly discuss the modifications that we introduce to investigate the interaction between trend inflation and determinacy. A detailed description of the model can be found in our online appendix.[2]

We introduce two key modifications to Christiano, Eichenbaum and Evans's (2005) model. The first is the treatment of indexation. Following Coibion and Gorodnichenko (2011), we assume indexation neither in prices nor in wages. This implies that the price (wage) setting behavior of those firms (households) not allowed to optimize is $P_t = P_{t-1}$ ($W_t = W_{t-1}$), where P_t (W_t) denotes the price of a final good (the wage) at time t. This assumption enhances the comparability of our results with Coibion and Gorodnichenko (2011). The second modification is that, again for the sake of comparability, we use Coibion and Gorodnichenko's (2011) hybrid Taylor rule specification for monetary

[1] Ascari and Sbordone (2014) survey the interaction of monetary policy, trend inflation, and determinacy.

[2] `https://www.dropbox.com/s/j9xfce9pyalg7sc/ONLINE_APPENDIX.pdf?dl=0`.

policy

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_{R_1}} \left(\frac{R_{t-2}}{R}\right)^{\rho_{R_2}} \left(\left(\frac{\mathbb{E}_t \Pi_{t+1}}{\Pi}\right)^{\psi_\pi} \left(\frac{Y_t}{Y_{t-1}\Lambda}\right)^{\psi_{gy}} \left(\frac{Y_t}{Y_t^{fp}} \frac{Y^{fp}}{Y}\right)^{\psi_y}\right)^{1-\rho_{R_1}-\rho_{R_2}} e^{\epsilon_t^R}, \tag{1}$$

where R_t denotes the nominal interest rate, Π_t is gross inflation, Y_t is output, Λ is the steady state growth of output, and Y_t^{fp} is the flexible price level of output. Note that the nominal interest rate responds to expected future inflation, to current output growth, and to the current output gap. Coibion and Gorodnichenko (2012) and Ascari, Castelnuovo and Rossi (2011) show that this specification is the best-fitting among a number of alternatives for the post-World War II U.S. data.

The log-linearized model can be expressed as

$$\mathbf{\Gamma_0}(\theta)\,\mathbf{S}_t = \mathbf{\Gamma_1}(\theta)\,\mathbf{S}_{t-1} + \mathbf{\Psi}(\theta)\,\varepsilon_t + \mathbf{\Pi}\eta_t, \tag{2}$$

where $\mathbf{S}_t$ is a vector including the variables of the model, θ is the vector of estimated structural parameters, ε_t is a vector of exogenous shocks, and η_t is a vector of the expectational errors (see our online appendix).[3] The model has seven exogenous shocks: a preference shock, a labor supply shock, an investment specific technological shock, a marginal productivity of investment shock, a technology shock, a monetary policy shock, and a government spending shock.

2.2 Estimation

We estimate our model using post-World War II U.S. data: sample 1960:Q1−2008:Q2. The aim of our empirical exercise is to obtain an empirically valid framework to assess the effects of trend inflation on the determinacy properties of the U.S. economy. We do not impose determinacy in the estimation phase; instead, we follow Lubik and Schorfheide (2004) and allow for indeterminacy when estimating the model.[4] Accordingly, the state space representation of our model and measurement equations are, respectively,

$$\mathbf{S_t} = \mathbf{T_1}(\theta)\,\mathbf{S_{t-1}} + \begin{bmatrix} \mathbf{T_0}(\theta) & \mathbf{T_I}(\theta) \end{bmatrix} \begin{bmatrix} \varepsilon_\mathbf{t} \\ \tilde{\mathbf{M}}\varepsilon_\mathbf{t} + \zeta_\mathbf{t}^* \end{bmatrix} \tag{3}$$

and

$$\mathbf{Y_t} = \mathbf{A}(\theta) + \mathbf{H}\,\mathbf{S_t} + \nu_t, \tag{4}$$

[3]To be clear, we solve the log-linearized version of the model around a positive trend inflation.

[4]We allow for indeterminacy of up to order two. Numerical simulations confirm that for an economically meaningful subset of the structural parameters, we can only find multiple equilibria if we allow for indeterminacy of degree two. According to our simulations, this is related to the absence of indexation in the model.

where $\mathbf{T_1}(\theta)$, $\mathbf{T_0}(\theta)$, $\mathbf{T_I}(\theta)$, and $\tilde{\mathbf{M}}$ characterize the solution of the model, $\zeta^*_\mathbf{t}$ is a vector of reduced-form sunspots shocks, $\mathbf{Y_t}$ denotes a vector of observables, $\mathbf{A}(\theta)$ and $\mathbf{H}$ are matrices mapping the model to the data. Relative to solution methods restricted to determinacy, Lubik and Schorfheide's (2004) methodology includes the following additional terms: $\mathbf{T_I}(\theta)$, $\tilde{\mathbf{M}}$, and $\zeta^*_\mathbf{t}$. $\mathbf{T_I}(\theta)$ is an impact matrix affecting the response of the economy to structural shocks and to sunspot shocks (described below), $\tilde{\mathbf{M}}$ is a matrix of arbitrary parameters that indexes the multiplicity of equilibria in the model, while $\zeta^*_\mathbf{t}$ is a vector of reduced-form sunspots shocks. The dimensions of the matrices described above are discussed in detail in the online appendix. The measurement equation contains i.i.d. measurement errors in the series for inflation and the log difference of real wage in order to control for the absence of time-varying mark-ups.[5] The vector of measurement errors is denoted by $\boldsymbol{\nu}_t = \left[0, 0, 0, \nu_{\pi,t}, 0, 0, \nu_{\tilde{W},t}\right]$, where $\nu_{\pi,t}$ denotes the measurement error for inflation and is assumed to have a normal distribution with mean zero and variance $\sigma^2_{\nu_\pi}$, while $\nu_{\tilde{W},t}$ denotes the measurement error for the growth rate of real wages and is assumed to follow a normal distribution with mean zero and variance $\sigma^2_{\nu_{\tilde{W}}}$.

The vector of observables $\mathbf{Y_t}$ contains data on the growth rates of output, consumption, and investment, which are all expressed in real, per capita terms, as well as on inflation, the nominal interest rate, and the growth rates of real wages. Our data corresponds to an updated version of the data used in Smets and Wouters (2007).

We report our estimation results in Tables 4 to 6 in the appendix. Overall, our estimates are similar to those found in the literature: see, for example, Christiano, Eichenbaum and Evans (2005), Smets and Wouters (2007), Justiniano, Primiceri and Tambalotti (2010), and Christiano, Eichenbaum and Trabandt (2013, 2014). We also perform Iskrev's (2010) identification test at the posterior mean of the estimated parameters, and we verified that all parameters are locally identified except for those associated with indeterminacy, that is $\tilde{\mathbf{M}}$ and the volatility of the reduced-form sunspot shocks.

3 Assessing Coibion and Gorodnichenko (2011)

3.1 Fixed-coefficients policy rules

In this section, we replicate the two main policy counterfactual experiments in Coibion and Gorodnichenko (2011) using our estimated model. We begin by describing the first counterfactual, which consists of computing the fraction of determinate equilibria for a given level of trend inflation for the periods pre-1979 and post-1982. Specifically, Coibion and Gorodnichenko (2011) take 10,000 draws from the joint asymptotically normal distribution of the policy parameters of the Taylor rule

[5] In the presence of time varying mark-ups and trend inflation without indexation, it is not possible to find a recursive representation of the price and wage setting equations.

described by equation 1 estimated by least squares.[6] The remaining parameters of their model are fixed at calibrated values. Conditional on those draws and the calibrated parameters, Coibion and Gorodnichenko (2011) compute the fraction of such draws for which the model is determinate. When replicating this counterfactual with our model, we draw from the same joint asymptotically normal distribution of the policy parameters as Coibion and Gorodnichenko (2011), but the remaining parameters of our model are set equal to the mean posterior estimates from our Bayesian estimation.[7]

Fraction of Determinate Equilibria: Counterfactual experiments							
	Taylor rule parameters					Trend inflation	
	ψ_π	ψ_{gy}	ψ_y	ρ_1	ρ_2	3 percent	6 percent
Pre-1979 period							
Baseline Taylor rule estimates	1.043	-0.002	0.525	1.340	-0.436	0.00	0.00
Switch inflation response	**2.201**	0.002	0.525	1.340	-0.436	62.60	0.00
Switch interest rate smoothing	1.043	0.002	0.525	**1.052**	**-0.129**	0.40	0.00
Switch output growth response	1.043	**1.561**	0.525	1.340	-0.436	0.50	0.00
Switch output gap response	1.043	0.002	**0.428**	1.340	-0.436	0.10	0.00
Zero output gap response	1.043	0.002	**0**	1.340	-0.436	35.60	5.50
Zero output growth response	1.043	**0**	0.525	1.340	-0.436	0.00	0.00
Zero output gap and growth resp.	1.043	**0**	**0**	1.340	-0.436	39.90	2.60
Post-1982 period							
Baseline Taylor rule estimates	2.201	1.561	0.428	1.052	-0.129	97.80	21.30
Switch inflation response	**1.043**	1.561	0.428	1.052	-0.129	8.00	0.00
Switch interest rate smoothing	2.201	1.561	0.428	**1.340**	**-0.436**	96.30	13.30
Switch output growth response	2.201	**0.002**	0.428	1.052	-0.129	83.20	1.50
Switch output gap response	2.201	1.561	**0.525**	1.052	-0.129	94.00	4.10
Zero output gap response	2.201	1.561	**0**	1.052	-0.129	99.90	99.90
Zero output growth response	2.201	**0**	0.428	1.052	-0.129	93.80	0.20
Zero output gap and growth resp.	2.201	**0**	**0**	1.052	-0.129	99.80	44.20

Table 1: Fraction of Determinate Equilibria: Counterfactual Experiments

Table 1 replicates Table 2 in Coibion and Gorodnichenko (2011) when the counterfactual is performed with our estimated model. The first column of Table 1 contains Taylor rules specifications for two subsamples, the pre-1979 period (1969–1978) in the upper panel, and the post-1982 (1983–2002) in the bottom panel. Columns two to six show the point estimates associated with each of the Taylor rule specifications and sample periods save for the numbers reported in bold which are either zeros or correspond to the point estimate coefficient of the post-1982 sample in the pre-1979 sample and vice versa. The last two columns show the fraction of parameters draws from the joint asymptotically normal distribution of the policy parameters of the Taylor rule for which the solution

[6]Coibion and Gorodnichenko (2011) use Greenbook forecasts of current and future macroeconomic variables prepared by staff members of the Federal Reserve Board to proxy for the expected variables. The data refer to the period from 1969 to 2002.

[7]The mean posterior estimates and the 5th and 95th percentiles are reported in Tables 4, 5, and 6 in the appendix.

of the model is determinate.

The probabilities reported in Table 1 offer solid support to the view put forward by Coibion and Gorodnichenko (2011). While a policy response to inflation larger than one fails to induce determinacy, it does succeed in pinning down a unique equilibrium if combined with a substantial reduction in the level of trend inflation. The "switch inflation response" counterfactual in the pre-1979 period (Table 1, second row) clearly shows that a more hawkish policy in the 1970s would have led the U.S. economy back to determinacy in the presence of a 3 percent value of trend inflation, but it would have failed to do so in the presence of a 6 percent trend inflation rate. Our simulations confirm that an aggressive response to inflation remains a valuable feature of systematic monetary policy. This is evident in the "switch inflation response" counterfactual for the post-1982 period, which shows how switching back to the weaker response to inflation of the 1970s would have dramatically decreased the likelihood of determinacy even in the presence of a 3 percent trend inflation rate.

Another claim by Coibion and Gorodnichenko (2011) is that a muted response to the output gap combined with an aggressive response to inflation increases the likelihood of determinacy. Our simulations also lend support to this claim, as shown by the scenario "zero output gap response" in the post-1982 period shown in Table 1. Indeed, conditional on a level of trend inflation equal to 6 percent, our model predicts an increase in the likelihood of determinacy from 21.30 percent to almost 100 percent.

Importantly, a more aggressive response to output growth enhances policymakers' ability to anchor inflation expectations. This can be seen by noticing that, in the presence of a high trend inflation value (6 percent), the post-1982 likelihood of determinacy drops from 21.30 percent (baseline scenario) to basically zero when the output growth response is muted. Similarly, the same likelihood drops from 99.9 percent in the "zero output gap response" scenario to 44.2 percent in the "zero output gap and growth response" scenario. Intuitively, reacting to output growth is stabilizing because dampening output growth requires increasing the real interest rate − due to the Euler equation − and thus strengthens the main rationale behind the Taylor principle, i.e., an increase in the nominal interest rate should bring about an increase in the real rate (see Coibion and Gorodnichenko (2011)). Moreover, trend inflation makes the price and wage setting behavior of firms and households more forward looking (see Ascari and Ropele (2007, 2009)). Hence, the expectation channel of monetary policy becomes more important. It is well understood that the prominent feature of optimal monetary policy under commitment is imparting inertia into policy actions in order to manage inflation expectations. Reacting to output growth achieves a similar goal in a rule-based scenario, because it makes the rule dependent on past values of output and thereby it disciplines inflation expectations (see Walsh (2003)).

The fact that history-dependent policies, like the ones featuring a positive response to output growth, are effective in dampening the likelihood of indeterminacy is confirmed by the exercises focusing on the degree of interest-rate smoothing. In particular, the switch to lower policy persistence, captured by the "switch interest rate smoothing" counterfactual in the post-1982 period is associated with a marked drop of the likelihood of determinacy, which moves from about 21 percent to 13 percent.

The results described above are consistent with other papers highlighting the importance of responding to output growth instead of the output gap (McCallum (2001), Orphanides (2002), Orphanides and Williams (2006), Coibion and Gorodnichenko (2011), and Sims (2013)). In particular, Sims (2013) shows that the optimal "simple and implementable" rule features no response to the output gap and a mild, but positive response to output growth, in a calibrated medium-scale New-Keynesian model abstracting from trend inflation. Our contribution is to show that rules with similar characteristics can almost completely eliminate sunspot fluctuations (associated with indeterminacy) induced by positive trend inflation, in the context of an estimated medium-scale New-Keynesian model that takes trend inflation into account.

3.2 Time-varying coefficients policy rule

Next, we consider the second counterfactual reported in Coibion and Gorodnichenko (2011). It consists of constructing a time series of the probability of determinacy for the U.S. economy from 1969 until 2002. To compute this probability, Coibion and Gorodnichenko (2011) first estimate the following Taylor rule with time-varying coefficients:

$$r_t = c_t + (1 - \rho_{1,t} - \rho_{2,t})(\psi_{\pi,t} E_t \pi_{t+1} + \psi_{gy,t} gy_t + \psi_{y,t} x_t) + \rho_{1,t} r_{t-1} + \rho_{2,t} r_{t-2} + \varepsilon_t, \tag{5}$$

where

$$c_t = (1 - \rho_{1,t} - \rho_{2,t})[(1 - \psi_{\pi,t})\overline{\pi}_t + \omega_t - \psi_{gy,t}\overline{gy} - \psi_{y,t}\overline{x}_t]. \tag{6}$$

Equation (5) describes the policy rate r_t as a function of a time varying intercept c_t, expected inflation $E_t\pi_{t+1}$, output growth gy_t and output gap x_t in the current quarter. Moreover, the rule features two lags of the policy rate and a white-noise shock ε_t. Equation (6) contains $\overline{\pi}_t$, the measure of trend inflation; ω_t, the equilibrium real interest rate; $\overline{gy}$, the target rate of growth of real GDP; and $\overline{x}_t$, the target level of the output gap. The policy parameters are assumed to follow random walk processes. Coibion and Gorodnichenko (2011) estimate model (5)-(6) via maximum likelihood to obtain filtered series of the coefficients for the policy parameters as well as the time-varying inflation target. Then, in each period Coibion and Gorodnichenko (2011) take 1,000 draws from the variance-covariance matrix of the policy parameters (and the time-varying inflation target parameter), and they couple this randomly drawn vector with the structural model to assess if the economy features a unique equilibrium. As in the previous counterfactual they calibrate the non policy structural parameters. Once the draws are obtained, the model is used to compute the fraction of them that are consistent with determinacy.[8]

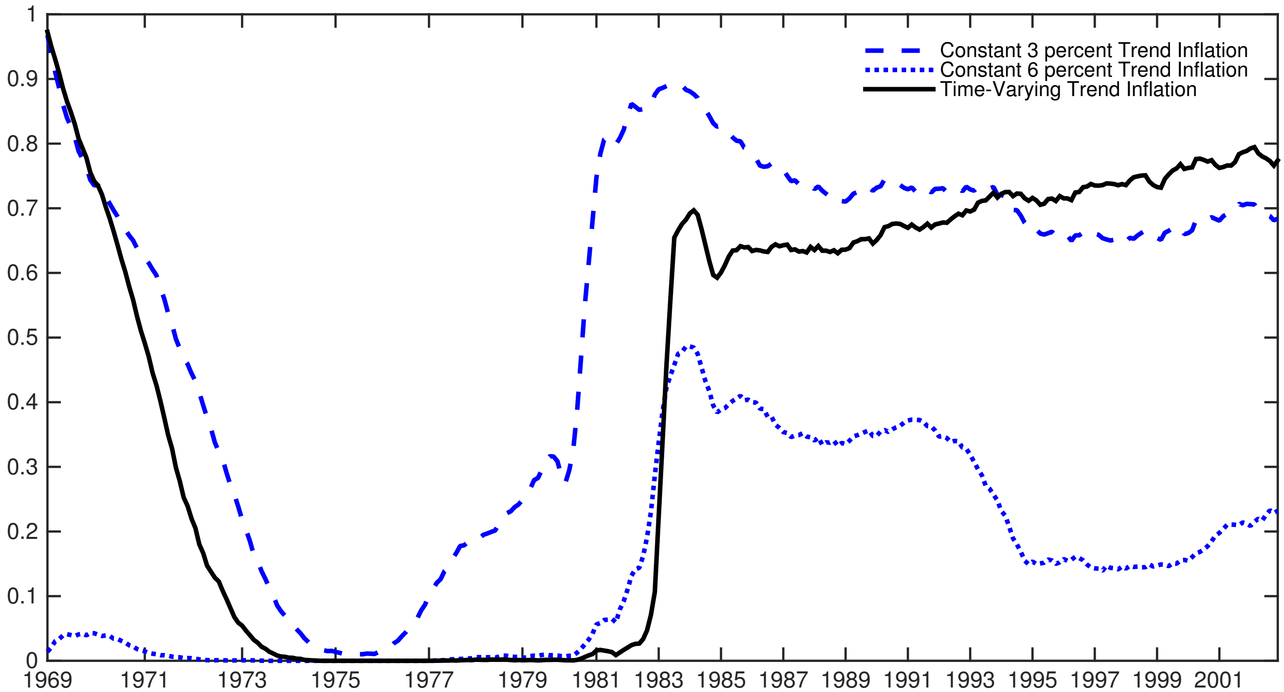

Figure 1: Probability of Determinacy Using Time-Varying Response Function by the Federal Reserve

Figure 1 replicates Figure 4 in Coibion and Gorodnichenko (2011).[9] The probabilities shown in Figure 1 are obtained by employing our medium scale New-Keynesian estimated model evaluating the non-policy parameters at their respective posterior means reported in the appendix.[10] The black solid line corresponds to the time-varying probability of determinacy described above, while the dashed and the dotted blue lines refer to the case in which the time-varying inflation target is replaced by a constant 3 percent and 6 percent, respectively. The solid line confirms that the U.S. economy was very likely in a state of indeterminacy during Arthur Burns and G. William Miller's chairmanships at the Federal Reserve (1970−1978 and 1978−1979 respectively) and regained significant stability after Paul Volcker's appointment. Thus, an estimated operational model confirms the empirical

[8]Note that, in conducting our simulations, we assume that agents do not take the parameter changes over time in the monetary policy rule into account. This is because of a technical issue. When parameters drift, multistep expectations are complicated to evaluate. Hence, following Cogley and Sargent (2008) and Cogley and Sbordone (2008), we assume agents to treat drifting parameters as if they would stay constant at their level at time t going forward in time. This is assumption, known as "anticipated utility" (Kreps (1998)), is standard in the macro learning literature (see Evans and Honkapohja (2001)). Cogley and Sargent (2008) note that this approximation is very good in models assuming certainty equivalence, which is what we implicitly do when log-linearizing around the steady-state.

[9]For expositional purposes, Coibion and Gorodnichenko (2011) report moving averages (across five Federal Open Market Committee (FOMC) meetings) of the resulting time-varying probability of determinacy.

[10]As it is common in the literature, some of the parameters are calibrated before estimation. Our appendix reports details on our calibrated and estimated parameters.

importance of trend inflation for the conquest of the U.S. Great Moderation, as argued by Coibion and Gorodnichenko (2011).

Note that the distance between the low trend inflation case (dashed line) and the high trend inflation case (dotted line) is significant also in the Volcker-Greenspan period. This indicates that trend inflation also matters conditional on the monetary policy stance during that period. The historical systematic component of monetary policy in the U.S. is not able to guarantee equilibrium uniqueness in the presence of moderate-to-high trend inflation levels. As we will show later (see Figure 2), this conclusion is also robust to the employment of our estimated policy rule reported in Table 2, that is, the one estimated using our medium-scale New Keynesian framework.

These results cast significant doubts on the possibility of raising the trend inflation to 4 percent to give policymakers more room to maneuver, unless one is able to engineer an implementable policy that can shield the U.S. economy against sunspot fluctuations due to a higher level of trend inflation. The next section proposes such an implementable Taylor rule.

4 Immunization to trend inflation: The TIIT rule

Our trend inflation immune Taylor (TIIT) rule is motivated by the findings in Kiley (2007), Ascari and Ropele (2009), and Coibion and Gorodnichenko (2011) about the interdependence between the systematic component of monetary policy, trend inflation, and determinacy. We have shown that such findings survive the scrutiny of an estimated medium-scale New-Keynesian model.

Parameter	ψ_π	ψ_y	ψ_{gy}	ρ_{R1}	ρ_{R2}
Value	1.73	0.01	0.37	1.02	−0.23
90 Percent Confidence Bands	[1.63;.1.81]	[0.00;0.02]	[0.28;0.47]	[0.97;1.08]	[−0.26;−0.19]

Table 2: Posterior of the Policy Parameters Sample: 1960Q1-2008Q2

We proceed as follows to design the TIIT rule. First, we set all policy parameters except for ψ_y and ψ_{gy} to their estimated values reported in Table 2. Then, inspired by the analytical and numerical insights explained in the next section, we set ψ_y^{TIIT} equal to 0 and we gradually increase the policy response to output growth until the Taylor principle is restored even when trend inflation equals 10 percent. We find such a threshold value for ψ_{gy}^{TIIT} to be equal to 1.25. The rule we find features an aggressive policy response to inflation and output growth, a substantial amount of interest rate smoothing, and a muted response to the output gap, that is, four desirable features of a rule aiming at avoiding indeterminacy. The coefficients of our TIIT rule are $\psi_\pi^{TIIT} = 1.73$, $\psi_y^{TIIT} = 0$, $\psi_{gy}^{TIIT} = 1.25$, $\rho_{R_1}^{TIIT} = 1.02$, $\rho_{R_2}^{TIIT} = -0.23$.

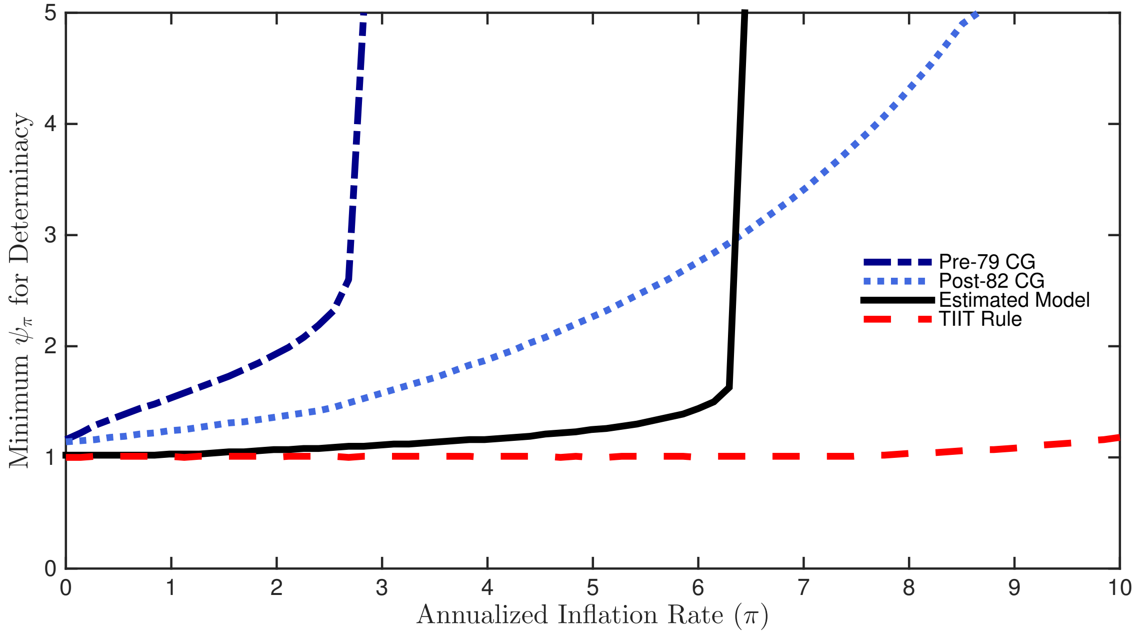

Figure 2: Trend Inflation Immune Policy

Note: CG refers to Coibion and Gorodnichenko (2011).

The power of our TIIT rule in reestablishing the Taylor principle is illustrated in Figure 2, which displays the minimum response to inflation required to induce determinacy at different values of trend inflation conditional on four different policy rules: Coibion and Gorodnichenko's (2011) pre-1979 policy rule, Coibion and Gorodnichenko's (2011) post-1982 policy rule, our estimated policy rule, and the TIIT rule. It is evident that the first three rules imply the violation of the standard Taylor principle for historically relevant values of trend inflation: higher trend inflation needs to be compensated by a higher response to inflation to guarantee determinacy.

Figure 2 also reveals the different effects of responding to the output gap or to output growth. The solid line associated with Coibion and Gorodnichenko's (2011) pre-1979 policy rule exhibits a smooth kink that divides the line into two parts: a first part where the response to inflation should continuously increase with trend inflation, and a second part where the line is almost vertical, signaling a maximum threshold level of trend inflation that can not be compensated by a higher response to inflation. Consistent with Ascari and Ropele (2009), the slope of the first part of the line depends on the response to the output gap: as trend inflation increases, the necessary response to inflation for determinacy is higher the stronger is the response to the output gap. The pre-1979 and post-1982 policy rules estimated by Coibion and Gorodnichenko (2011) are characterized by a sizable response to the output gap and, as a consequence, the first part of the line notably slopes upward. Instead, our estimated policy, shown by dashed-dotted line, does not respond to the output gap − that is, the first part of the line is rather flat up to 6 percent trend inflation, which is close to the maximum value of trend inflation estimated by Coibion and Gorodnichenko (2011), i.e. 7 percent.

The argument above suggests that the threshold level of sustainable trend inflation is mainly determined by the response to output growth: the higher such a response, the more this threshold is shifted to the right. For example, when using the pre-1979 policy rule in Coibion and Gorodnichenko (2011), which features a muted response to output growth, the threshold is reached at 3 percent trend inflation, but when using the policy rule from our estimated model, which features a stronger response to output growth, the threshold is reached at 6 percent trend inflation.

Using the TIIT rule, a response to inflation just above one is sufficient to restore determinacy, because it combines both (i) a zero response to output gap, implying that the minimum ψ_π do not have to gradually increase with trend inflation for values below the threshold trend inflation level, and (ii) a sizable response to output growth, implying that the threshold level is shifted to the right of historically relevant trend inflation levels. A higher output growth response is basically shifting the minimum ψ_π line rightwards in Figure 2.

Next, we replicate the counterfactual described by the solid black line in Figure 1, but using the four specifications for the Taylor rule described above instead of the time-varying Taylor rule estimated by Coibion and Gorodnichenko (2011). Figure 3 shows that our TIIT rule is able to yield determinacy even in the presence of historically high values of trend inflation, like those estimated by Coibion and Gorodnichenko (2011) for the 1970s.

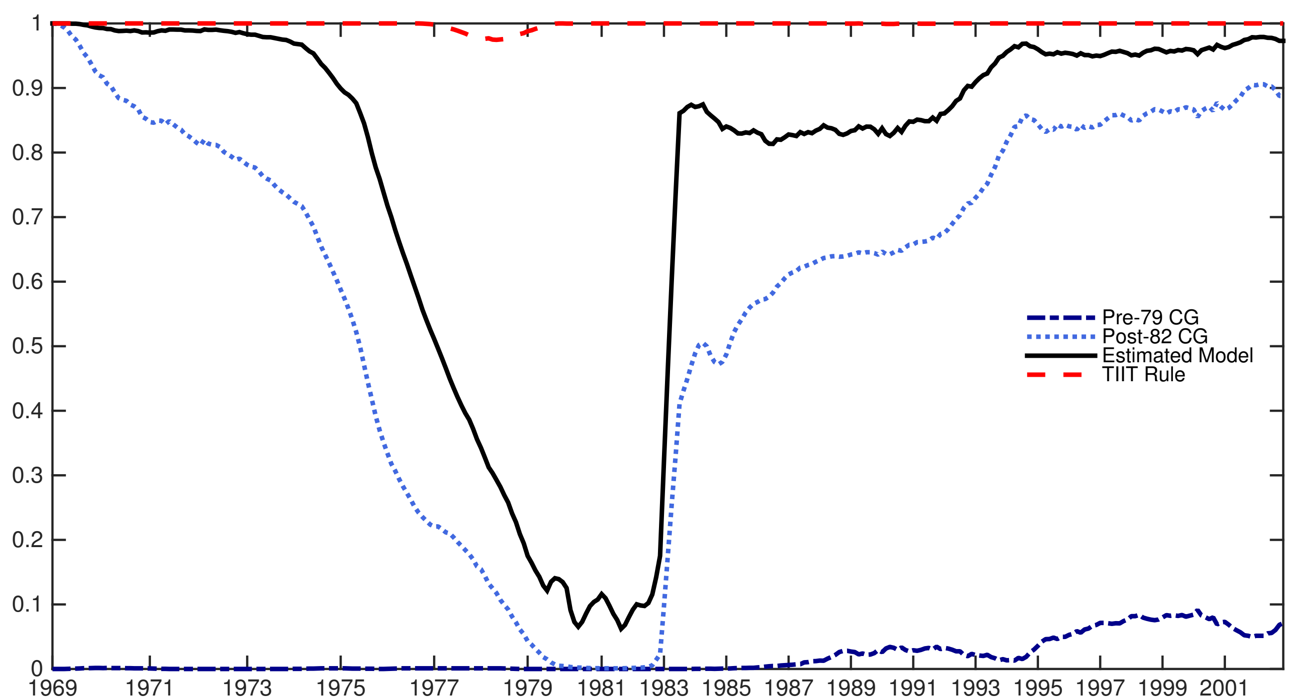

Figure 3: Probability of Determinacy Using Time-Varying Response Function by the Federal Reserve

Note: CG refers to Coibion and Gorodnichenko (2011).

5 Why does the TIIT rule work?

In this section, we provide analytical intuition to understand why the TIIT rule works. As anticipated in the previous Section, the rule has two key components. The first is a zero response to the output gap motivated by the work of Ascari and Ropele (2009), who show that Taylor rules that respond to the output gap are destabilizing. The second is a strong response to deviations of current output growth from the potential growth rate. We discussed before that responding to output growth introduces history dependence in the rule, which makes the system less forward looking and hence less prone to instability, similar to the case of the inertial component of Taylor rules. Showing how this operates exactly with analytical results is a challenge. Nevertheless, we will show that under certain assumptions, determinacy hinges on a theoretical threshold for the response to output growth.

Consider the following representation of the small-scale New-Keynesian model described in Ascari and Ropele (2009), which we extend so that the Taylor rule also includes a response to output growth:

$$\mathbf{A}\begin{bmatrix}\mathbf{x}_{t+1}\\ \mathbf{k}_t\end{bmatrix} = \begin{bmatrix}\mathbf{x}_t\\ \mathbf{k}_{t-1}\end{bmatrix}, \tag{7}$$

where β is the discount factor, Π is the level of trend inflation, η_p is the elasticity of substitution between intermediate goods, ν_p is the Calvo parameter and $\lambda = \frac{\left(1-\nu_p\Pi^{(\eta_p-1)}\right)(1-\nu_p\beta\Pi^{\eta_p})}{\nu_p\Pi^{(\eta_p-1)}}$.

Proposition 1. *Assume that $0 < \nu_p < 1$, $0 < \beta < 1$, $1 < \eta_p$, $\nu_p = \frac{1}{\beta\Pi^{\eta_p}} - \delta$, $0 < \delta < \frac{1}{\beta\Pi^{\eta_p}}$, and $\psi_y = 0$. Then, as $\delta \to 0$ there is a unique local stable equilibrium if and only if*

$$\begin{aligned}\psi_{gy} &> 1\\ \frac{D + \eta_p(\Pi-1)(\beta\Pi-1) + (\beta+1)\Pi}{2\beta\Pi} &> 1\\ \frac{-D + \eta_p(\Pi-1)(\beta\Pi-1) + (\beta+1)\Pi}{2\beta\Pi} &> 1\end{aligned}$$

where $D = \sqrt{(\eta_p(\Pi-1)(\beta\Pi-1) + (\beta+1)\Pi)^2 - 4\beta\Pi^2}$.

Proof. The proof follows directly from combining the eigenvalues of the characteristic equation of A at $\nu_p = \frac{1}{\beta\Pi^{\eta_p}}$, with the fact that the eigenvalues at $\nu_p = \frac{1}{\beta\Pi^{\eta_p}} - \delta$ are continuous on δ; see Theorem 1 in Zedek (1965). □

Corollary 1. *Under the assumptions of Proposition 1, as $\delta \to 0$ there is a unique local stable equilibrium only if the response to output growth is greater than one.*

There are two important remarks about the result derived in Proposition 1. First, we need a limit argument on δ: for the steady state of the model to be well defined, it must be the case that

$\nu < \frac{1}{\beta\Pi^\theta}$. As a consequence, the limit here should be understood to be a limit $\nu \to \frac{1}{\beta\Pi^\theta}$ from below. This knife-hedge limit argument is useful for our purposes, because the zeros of a polynomial are continuos functions of the polynomial parameters as shown by Zedek (1965).

Second, note that the response to inflation ψ_π does not enter into the conditions required for determinacy. We have explicitly chosen this feature for tractability reasons. This is the main reason for assuming $\nu = \frac{1}{\beta\Pi^\theta} - \delta$: as $\delta \to 0$, $\lambda \to 0$, therefore, ψ_π does not enter into the characteristic equation of $\mathbf{A}$. Assuming $\lambda \to 0$ comes at a cost because it implies that in the limit, $\lambda = 0$, and as a result inflation is purely forward looking and independent of output and real marginal costs. Nevertheless, by abstracting from the feedback from the real variables (output and real marginal costs) to inflation, we are able to show analytically how a strong response to output growth leads to determinacy. Specifically, our channel shows that a strong response to output growth becomes crucial if inflation expectations in the economy become less sensitive to real variables, which could be the case in high inflation environments.

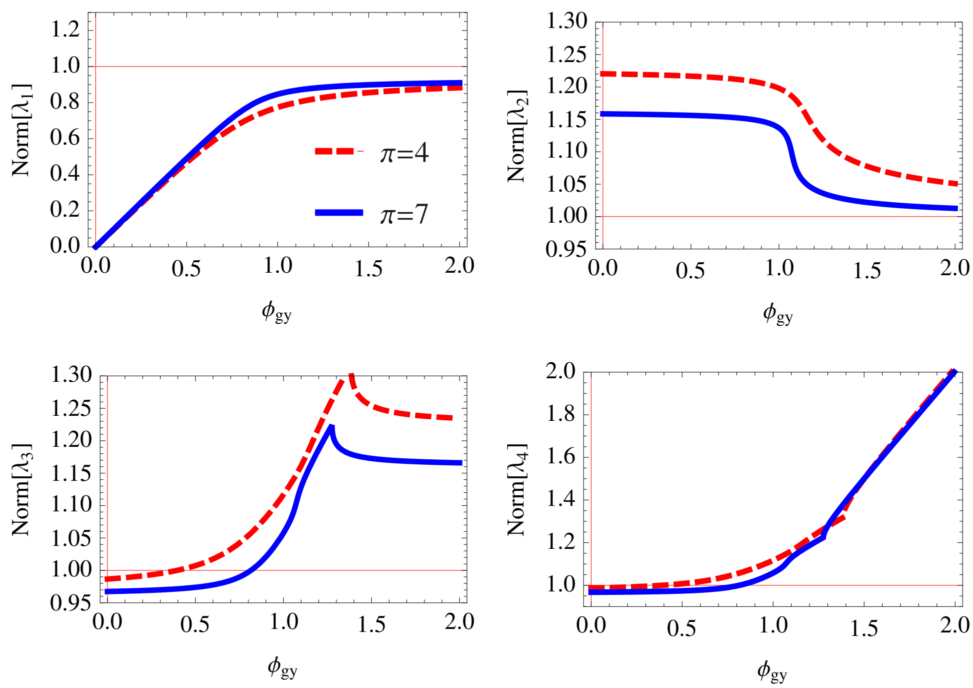

Figure 4: Eigenvalues

The third remark is that the threshold that we find for ψ_{gy} is independent of the level of trend inflation. This is again a byproduct of assuming that inflation is purely forward looking. Once we allow inflation to depend on the real side of the economy, there is no tractable analytical solution. We can however show numerically that there is a positive relation between the threshold for ψ_{gy} and trend inflation, as suggested by the discussion in the previous section. Figure 4 shows the norm of the eigenvalues corresponding to the linear system described by equation 7 for two values of trend inflation (4 and 7 percent annualized) as a function of the response to output growth, conditional on the following calibration: ν_p equal to 0.80, β equal to 0.99, η_p equal to 10, ψ_y equal to 0, and $\psi_\pi = 1.5$. Recall that since the system has three controls and one predetermined variable, stability requires having three eigenvalues outside the unique circle and one inside it. It is clear from Figure 4 that one eigenvalue is always inside the unit circle, while three of them are outside the unit circle only if a certain threshold on ψ_{gy} is satisfied. Moreover, the threshold is increasing in the level of trend inflation. Note that when annualized trend inflation, π, is equal to 7 percent, the threshold for ψ_{gy} necessary for determinacy shifts to the right relative to the case in which annualized trend inflation is equal to 4 percent.

6 Conclusion

We have shown that Coibion and Gorodnichenko's (2011) alternative interpretation of the Great Moderation holds in an estimated medium-scale model à la Christiano, Eichenbaum and Evans (2005). Importantly, we have also shown that in our model a simple rule featuring an aggressive response to output growth and a muted reaction to the output gap would be able to shield the occurrence of sunspot shocks in the presence of levels of trend inflation up to 10 percent.

Our policy rule provides a new element to the debate on the pros and cons of the 4 percent inflation target recently discussed by Blanchard, Dell'Ariccia and Mauro (2010), Krugman (2013), and Ball (2014). Our simulations show that, conditional on such a rule, bringing trend inflation to 4 percent without inducing indeterminacy is feasible in the context of a medium-scale New Keynesian model.

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7 Appendix

7.1 Calibrated Parameters

Let us begin by noting that the two key parameters of this study, the indexation parameters for the price of intermediate goods and wages, are set equal to zero in order to allow for the highest possible distortions associated with trend inflation. Accordingly, $\iota_p = 0$ and $\iota_w = 0$. In addition, wages are not indexed by growth, $\iota_Z = 0$, as in Christiano, Eichenbaum and Trabandt (2013). The capital share α of the economy and the depreciation rate of capital δ are set equal to 0.225, and 0.025, respectively, based on Schmitt-Grohe and Uribe (2012). The steady-state government consumption in GDP η_G is set equal to 0.21, which is equal to the average in our sample. The steady state growth rate of the economy Λ_Z, is calibrated to match the average growth rate of output in our sample. Similarly, the steady state growth rate of the investment specific shock, Λ_μ, is calibrated to match the average relative price of investment in terms of consumption in our sample, computed as in Justiniano, Primiceri and Tambalotti (2010). Conditional on this calibration, the inverse of elasticity of substitution of capital utilization with respect to the rental rate of capital σ_a is not identified at the posterior mean of the parameter estimates. As a consequence, we set this parameter equal to the value used in Smets and Wouters (2007), which is equal to 1.1739. Table 3 summarizes the calibrated parameters.

Parameter	ι_p	ι_w	ι_Z	α	δ	η_G	Λ_Z	Λ_μ	σ_a
	0	0	0	0.225	0.025	0.21	1.0046	1.0043	1.1739

Table 3: Calibrated Parameters

7.2 Parameter Estimates

Table 4 shows the estimation results for the structural parameters of our benchmark model, Table 5 shows the results for the exogenous processes parameters, and Table 6 shows the results for the parameters that characterize the indeterminacy region. Table 7 briefly describes the parameters, for details see the online appendix.

	posterior			Prior		
Parameter	Mean	5 percent	95 percent	Distribution	Mean	Std Dev
ψ_π	1.73	1.63	1.81	Gamma	1.70	0.30
ψ_y	0.01	0.00	0.02	Gamma	0.13	0.10
ψ_{gy}	0.37	0.28	0.47	Gamma	0.13	0.10
ρ_{R1}	1.02	0.97	1.08	Normal	1.00	0.20
ρ_{R2}	-0.23	-0.26	-0.19	Normal	0.00	0.20
κ	3.62	3.46	3.73	Gamma	3.00	0.75
ν_p	0.82	0.81	0.84	Beta	0.50	0.20
ν_w	0.60	0.52	0.65	Beta	0.50	0.20
$100\log(\Pi)$	0.75	0.64	0.87	Gamma	0.62	1.00
b	0.91	0.90	0.92	Beta	0.70	0.10
$(\eta_p-1)^{-1}$	0.28	0.26	0.31	Normal	0.15	0.05
$(\eta_w-1)^{-1}$	0.22	0.17	0.29	Normal	0.15	0.05
τ	1.36	1.29	1.43	Gamma	2.00	0.75
$100(\beta^{-1}-1)$	0.13	0.10	0.15	Gamma	0.25	0.10

Table 4: Estimated Structural Parameters (Sample: 1960:Q1–2008:Q2)

	posterior			Prior		
Parameter	Mean	5 percent	95 percent	Distribution	Mean	Std Dev
ρ_G	0.99	0.98	0.99	Beta	0.50	0.20
ρ_A	0.05	0.04	0.06	Beta	0.50	0.20
ρ_d	0.21	0.18	0.24	Beta	0.50	0.20
ρ_{d_L}	0.97	0.96	0.98	Beta	0.50	0.20
ρ_{mI}	0.93	0.92	0.95	Beta	0.50	0.20
ρ_μ	0.78	0.76	0.81	Beta	0.50	0.20
$100\sigma_d$	4.41	4.31	4.55	Gamma	0.10	2.00
$100\sigma_{d_L}$	3.03	2.86	3.19	Gamma	0.10	2.00
$100\sigma_A$	0.98	0.92	1.06	Gamma	0.10	2.00
$100\sigma_{mI}$	7.04	6.99	7.08	Gamma	0.10	2.00
$100\sigma_\mu$	0.90	0.82	0.97	Gamma	0.10	2.00
$100\sigma_R$	0.21	0.19	0.23	Gamma	0.10	2.00
$100\sigma_G$	2.28	2.16	2.41	Gamma	0.10	2.00
$100\sigma_{obs_\pi}$	0.19	0.17	0.21	Gamma	0.10	2.00
$100\sigma_{obs_w}$	0.65	0.61	0.71	Gamma	0.10	2.00

Table 5: Estimated Exogenous Process (Sample: 1960:Q1–2008:Q2)

	posterior			Prior		
Parameter	Mean	5 percent	95 percent	Distribution	Mean	Std Dev
$100\sigma_{\zeta_1}$	4.01	4.00	4.01	Gamma	0.10	2.00
$100\sigma_{\zeta_2}$	3.98	3.97	3.99	Gamma	0.10	2.00
$M_{1,d}$	0.02	0.00	0.03	Normal	0.00	1.00
M_{1,d_L}	0.00	-0.01	0.01	Normal	0.00	1.00
$M_{1,A}$	-0.03	-0.04	-0.01	Normal	0.00	1.00
$M_{1,mI}$	-0.01	-0.02	-0.00	Normal	0.00	1.00
$M_{1,\mu}$	-0.01	-0.02	-0.00	Normal	0.00	1.00
$M_{1,R}$	0.00	-0.01	0.01	Normal	0.00	1.00
$M_{1,G}$	0.01	-0.00	0.01	Normal	0.00	1.00
$M_{2,d}$	0.01	0.00	0.02	Normal	0.00	1.00
M_{2,d_L}	-0.01	-0.02	-0.00	Normal	0.00	1.00
$M_{2,A}$	-0.01	-0.02	-0.00	Normal	0.00	1.00
$M_{2,mI}$	0.01	0.00	0.02	Normal	0.00	1.00
$M_{2,\mu}$	-0.00	-0.01	0.00	Normal	0.00	1.00
$M_{2,R}$	0.01	0.00	0.03	Normal	0.00	1.00
$M_{2,G}$	0.00	-0.01	0.01	Normal	0.00	1.00

Table 6: Indeterminacy Parameters (Sample: 1960:Q1–2008:Q2)

Parameter	Description
ψ_π	Taylor rule: Response to inflation
ψ_y	Taylor rule: Response to the output gap
ψ_g	Taylor rule: Response to the output growth
ρ_{R1}	Taylor rule: Interest rate smoothing
ρ_{R2}	Taylor rule: Interest rate smoothing
κ	Capital adjustment cost
ν_p	Calvo price parameter
ν_w	Calvo wage parameter
Π	Steady state gross inflation
b	Habit persistence
η_p	Elasticity of substitution between intermediate goods
η_w	Elasticity of substitution between labor types
τ	Inverse of the Frisch elasticity
β	Subjective discount factor
ρ_G	Autoregressive parameter of government expenditure shock.
ρ_A	Autoregressive parameter of neutral technology shock
ρ_d	Autoregressive parameter of preference shock
ρ_{d_L}	Autoregressive parameter of labor preference shock
ρ_{mI}	Autoregressive parameter of marginal efficiency of investment shock
ρ_μ	Autoregressive parameter of investment specific shock
$100\sigma_d$	Variance of preference shock
$100\sigma_{d_L}$	Variance of labor preference shock
$100\sigma_A$	Variance of neutral technology shock
$100\sigma_{mI}$	Variance of marginal efficiency of investment shock
$100\sigma_\mu$	Variance of investment specific shock
$100\sigma_R$	Variance of monetary policy shock
$100\sigma_G$	Variance of government expenditure shock
$100\sigma_{obs_\pi}$	Variance of measurement error of inflation
$100\sigma_{obs_w}$	Variance of measurement error of real wage growth
$100\sigma_{\zeta_1}$	Variance of sunspot shock (Indeterminacy parameter)
$100\sigma_{\zeta_2}$	Variance of sunspot shock (Indeterminacy parameter)
$M_{1,d}$	Indeterminacy parameter
M_{1,d_L}	Indeterminacy parameter
$M_{1,A}$	Indeterminacy parameter
$M_{1,mI}$	Indeterminacy parameter
$M_{1,\mu}$	Indeterminacy parameter
$M_{1,R}$	Indeterminacy parameter
$M_{1,G}$	Indeterminacy parameter
$M_{2,d}$	Indeterminacy parameter
M_{2,d_L}	Indeterminacy parameter
$M_{2,A}$	Indeterminacy parameter
$M_{2,mI}$	Indeterminacy parameter
$M_{2,\mu}$	Indeterminacy parameter
$M_{2,R}$	Indeterminacy parameter
$M_{2,G}$	Indeterminacy parameter

Table 7: Description of Parameters (See online appendix for details)