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Abstract

Using an estimated DSGE model that features monetary and fiscal policy interactions and allows for equilibrium indeterminacy, we find that a passive monetary and passive fiscal policy regime prevailed in the pre-Volcker period while an active monetary and passive fiscal policy regime prevailed post-Volcker. Since both monetary and fiscal policies were passive pre-Volcker, there was equilibrium indeterminacy that gave rise to self-fulfilling beliefs and resulted in substantially different transmission mechanisms of policy as compared to conventional models: unanticipated increases in interest rates increased inflation and output while unanticipated increases in lump-sum taxes decreased inflation and output. Unanticipated shifts in monetary and fiscal policies however, played no substantial role in explaining the variation of inflation and output at any horizon in either of the time periods. Pre-Volcker, in sharp contrast to post-Volcker, we find that a time-varying inflation target does not explain low-frequency movements in inflation. Finally, in a counterfactual exercise, we show that had the monetary policy regime of the post-Volcker era been in place pre-Volcker, inflation volatility would have been lower by 40% and the rise of inflation in the 1970s would not have occurred.

JEL Classification: C52, C54, E31, E32, E52, E63

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1 Introduction

Macroeconomic models that are estimated and used for monetary policy analysis typically abstract from non-trivial monetary and fiscal policy interactions. A theoretical literature starting with the work of Sargent and Wallace (1981) and Aiyagari and Gertler (1985) has however, long emphasized that monetary and fiscal policies jointly determine equilibrium model dynamics. Moreover, the recent crisis, which has brought to the fore issues of monetary and fiscal policy interactions due to unconventional monetary policy actions that can have significant effects on the government budget and great uncertainty about the future course of fiscal policy, provides an additional impetus to model monetary and fiscal policies jointly in macroeconomic models geared towards policy analysis.

Motivated by these considerations, we extend a standard DSGE model that features nominal and real rigidities to include an explicitly specified description of fiscal policy. Similar to the standard feedback rule for monetary policy that governs how nominal interest rates respond to inflation and output, our model features a feedback rule for fiscal policy that determines how taxes respond to debt and output, and how government spending responds to output. In such a set-up, as shown by Leeper (1991), Sims (1994), and Woodford (1995), the equilibrium model dynamics depend crucially on monetary and fiscal policy stances, that is, the strength with which policies respond to the state of the economy. Equilibrium in our model is determinate under two cases: either when both the interest rate response to inflation and the tax response to debt are strong (an active monetary and passive fiscal policy regime) or when both the responses are weak (a passive monetary and active fiscal policy regime). Indeterminacy of equilibrium arises when a weak interest rate response to inflation is coupled with a strong response of taxes to debt (a passive monetary and passive fiscal policy regime).\(^1\)

We use this model as a laboratory to answer four broad set of questions. First, what monetary and fiscal policy regimes characterized post-War U.S. data? Second, what were the monetary and fiscal policy transmission mechanisms over time? Third, which shocks were the primary sources of short and long-run variation in inflation? Fourth, what would have been the path of inflation, especially with regards to the rise of inflation in the 1970s, under a (counterfactual) monetary policy regime different from the estimated one?

We conduct our empirical analysis, following a large literature, by splitting the data into two time-periods based on the timing of Paul Volcker’s chairmanship at the Federal Reserve: a pre-Volcker period and a post-Volcker period.\(^2\) Using likelihood based methods, we fit

\(^1\) We use the language of Leeper (1991) in characterizing policies as active or passive. The exact bounds for active and passive policies are model-specific and we make these definitions precise later in the paper after introducing the model.

\(^2\) Following this literature, we define the pre-Volcker sample from 1960:Q1 to 1979:Q2 and a post-Volcker sample from 1982:Q4 onwards. An alternative approach to split-sample estimation is a recurrent regime-
our model to data on both conventional and fiscal variables. In particular, we use the likelihood based estimation method proposed by Lubik and Schorfheide (2004) that allows for indeterminacy in a DSGE model. Allowing for the possibility of indeterminacy in an estimated DSGE model that features monetary and fiscal policy interactions is a distinct contribution of our paper, and one that matters for our results. Using a Bayesian model comparison exercise, we first assess the best-fitting policy regime in the two time-periods. With the posterior distribution of the parameters of the best-fitting model at hand, we then conduct several impulse response, variance decomposition, and counterfactual analyses.

Our main results are as follows. First, using Bayesian model comparison we find that pre-Volcker, the best-fitting model is a passive monetary and passive fiscal policy regime, while post-Volcker, it is an active monetary and passive fiscal policy regime. As a result, there was equilibrium indeterminacy in the pre-Volcker era. Thus, our results are consistent with those of Clarida, Gali, and Gertler (2000), who using limited information methods, provide evidence for a weak response of interest rates to expected inflation in the pre-Volcker period. They are also aligned with those of Coibion and Gorodnichenko (2011), who estimate a Taylor rule using Greenbook forecasts, and Boivin and Giannoni (2006), who use an impulse response matching method. Finally, in a likelihood-based inference context, our results are also consistent with those of Lubik and Schorfheide (2004). As we discuss below however, our results on the transmission mechanisms of monetary and fiscal policies in the pre-Volcker period are in contrast to the literature.

Second, using impulse response analysis we show that the transmission mechanisms of monetary and fiscal policies were substantially different in the two time periods due to different prevailing policy regimes. In particular, equilibrium indeterminacy pre-Volcker substantially

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3We are obviously not the first ones to estimate a monetary DSGE model with an explicit description of fiscal policy. In fact, this literature has advanced rapidly recently, with a more detailed description of fiscal policy compared to ours. For important recent contributions, see, Drautzberg and Uhlig (2011), Traum and Yang (2011b), and Zubairy (2010). In addition, Fernandez-Villaverde et al (2012) estimate fiscal rules with volatility shocks and feed them into a standard medium-scale DSGE model and Leeper, Richer, and Walker (2012) analyze effects of fiscal foresight. Our relative contribution is to estimate a DSGE model with an explicit description of both monetary and fiscal policies while allowing for multiple equilibria.

4Lubik and Schorfheide (2004) assess the role of equilibrium indeterminacy due to passive monetary policy but abstract from fiscal policy while Traum and Yang (2011a) tackle monetary and fiscal policy interactions but abstract from the possibility of equilibrium indeterminacy. Bianchi and Ilut (2012) estimate a model with a one-time unanticipated change from an active fiscal to passive fiscal regime and use it to explain the rise of inflation in the 1970s, while also abstracting from equilibrium indeterminacy. We make it clear later in the paper why allowing for both fiscal policy and indeterminacy is crucial for our results in the pre-Volcker period.

5Some preliminary and partial results of this research program, based on a simpler model, appear in Bhattarai, Lee, and Park (2012a).

altered the propagation mechanism of fundamental shocks in the economy due to self-fulfilling beliefs of the agents. For example, while pre-Volcker, an unanticipated increase in interest rates led to an increase in output and inflation, post-Volcker, it led to a decline in output and inflation. Moreover, while pre-Volcker, an unanticipated increase in the (lump-sum) tax revenues-to-output ratio led to a decline in output and inflation, post-Volcker, it had no effects on output or inflation.

Pre-Volcker, the response of the economy to unanticipated policy shifts was thus similar to that predicted by the fiscal theory of the price level (FTPL).\footnote{Canzoneri, Cumby, and Diba (2011) is a recent survey of the FTPL literature. In our model, FTPL is operative under a passive monetary and active fiscal policy regime. We find that our estimated best-fitting model pre-Volcker, a passive monetary and passive fiscal policy regime, mimics a passive monetary and active fiscal policy regime in important dimensions, even though it is not technically one where the FTPL has to be operative for sure.} Under FTPL, an increase in interest payments due to a contractionary monetary policy increases spending by agents because of a positive wealth effect. This then leads to an increase in inflation and output. Moreover, shifts in fiscal policy influence inflation and output under FTPL due to wealth effects. In contrast, post-Volcker, the response of the economy followed the predictions of standard models of price determination.

Our findings in an estimated DSGE model that pre-Volcker, inflation increased both on impact and afterwards following a monetary contraction and unanticipated movements in lump-sum taxes affected both inflation and output is new to the literature. For example, Lubik and Schorfheide (2004), who only model monetary policy, find that in their indeterminate model in the pre-Volcker period, inflation does not rise on impact following an interest rate increase.\footnote{Belaygorod and Dueker (2009) – who did not include fiscal policy explicitly in the model – find that compared to Lubik and Schorfheide (2004), using a different prior on parameters governing indeterminacy does result in inflation rising on impact following an interest rate increase. Our pre-Volcker results in this paper are robust to the priors used for these parameters. As we make clear later in the paper, this strong identification in our exercise is due to the inclusion of fiscal variables in our model.} Our results are in fact quite close to those obtained from the identified VAR literature. Since the work of Sims (1992), it has been observed that in many VAR specifications, inflation tends to increase on impact following a contractionary monetary policy shock. This has been dubbed the "price puzzle" in the literature since it goes against the predictions of the standard models of price determination. Hanson (2004) in a comprehensive study showed that this "price puzzle" seems to be a feature only of the pre-Volcker period and not for the entire post-War U.S. data.\footnote{Boivin and Giannoni (2006) contains a similar result.} Our results are thus consistent with his findings and moreover, have a model based interpretation. In addition, Sims (2011) provides some VAR based evidence on predictory power of fiscal variables in explaining U.S. inflation. We provide complementary evidence from our estimated model on this front, albeit only for the pre-Volcker period.

Third, using variance decomposition analysis we find that in both the time-periods and at
both the short and long-run, unanticipated shifts in monetary and fiscal policies play only a minor role in explaining the dynamics of inflation and output.\textsuperscript{10} For example, for inflation, pre-Volcker, monetary and tax policy shocks explain less than 11\% of the variation at both horizons. Post-Volcker, both the shocks explain basically no variation at either horizons. For output growth, pre-Volcker, monetary policy shocks explain around 1.6\% and tax policy shocks explain around 4.7\% of the variation in both the short and long-run. Post-Volcker, the monetary shock explains around 2.5\% of the variation at both horizons while fiscal policy shocks explain basically no variation in output growth.

Our result that random variations in monetary policy do not explain much of the fluctuations in the data, is consistent with the results in the identified VAR literature, for example, Sims and Zha (2006a) and also with the estimated DSGE literature, for example, Smets and Wouters (2007). That the same conclusion also holds for random variations in fiscal policy, given by unanticipated movements in taxes, is new to our knowledge, to the estimated DSGE literature that features both monetary and fiscal policies.\textsuperscript{11} While we find that random disturbances to policy do not matter significantly, this does not imply at all that the systematic component to policy is also unimportant. In fact, to the contrary, as we show later in the paper, the propagation mechanisms of many shocks are substantially different in the two time-periods. This is exactly because the systematic responses of policy were dramatically different pre and post-Volcker, with different monetary and fiscal policy regimes operative in the two time-periods. We also want to emphasize a similar point for indeterminacy. For example, for the pre-Volcker period, sunspot shocks introduced due to indeterminacy play a minor role in explaining the dynamics of inflation and output. While we thus find that sunspot shocks do not matter quantitatively, this does not necessarily imply that indeterminacy is not significant for explaining inflation and output dynamics in the pre-Volcker period. In fact, indeterminacy due to passive monetary and fiscal policy leads to fundamentally different propagation mechanism of fundamental shocks, as agents’ self-fulfilling beliefs play a key role in model dynamics.

Fourth, pre-Volcker, in sharp contrast to post-Volcker, we find that variations in the inflation target do not explain low-frequency movements in inflation.\textsuperscript{12} In the recent DSGE literature, a consensus finding has emerged that the long-run variation in inflation is ex-

\textsuperscript{10}We focus on a 4 and 40 quarter horizon in our variance decomposition results.

\textsuperscript{11}Our results are complementary to those of Leeper, Plante, and Traum (2010), who use a real model with a rich specification of fiscal policy. While detailed variance decomposition results are not available in the paper, one can reasonably infer from their impulse response analysis that random variation in fiscal policy might not have had quantitatively significant effects on macroeconomic variables. Their use of a real model though precludes a comparison with our results in terms of inflation.

\textsuperscript{12}In Bhattarai, Lee, and Park (2012b), we provide several analytical results that characterize the properties of inflation dynamics, in particular the role of a time-varying inflation target, in a simple sticky price DSGE model under different policy regimes.
plained mostly by changes in the inflation target in the monetary policy reaction function. For example, Ireland (2007) and Cogley, Primiceri, and Sargent (2010) show that both pre-and post-Volcker, smoothed inflation target tracks actual inflation remarkably well. While we find a similar result in the post-Volcker period, our results are quite different in the pre-Volcker era: changes in the inflation target explain virtually none of the long-run variation in inflation. The major reason for this difference is that we explicitly allow for the possibility of indeterminacy while estimating our model that features both monetary and fiscal policies. When the operative regime is active monetary and passive fiscal policy, as is the implicit assumption in Ireland (2007) and Cogley, Primiceri, and Sargent (2010) for both the time-periods, then changes in the inflation target do explain inflation in the long-run since monetary policy fully controls inflation dynamics. Our best-fitting estimated model in the pre-Volcker features indeterminacy due to passive monetary policy, however. In this case, consider a decrease in the inflation target. This, through the central bank reaction function, does tend to increase the interest rate. An increase in the interest rate in this model though, as we pointed out above, tends to increase inflation. Thus, inflation target movements do not track actual inflation in the long-run.\footnote{Davig and Doh (2011) do not find a significant role for time-varying inflation target in explaining low-frequency inflation movements in post-War U.S. data while allowing for regime-switching in both policy coefficients and volatility. Our result, in a set-up that considers sub-sample estimation, is different from theirs since we do find a role for a time-varying inflation target in the post-Volcker era.}

Fifth, we find that the primary sources of short and long-run variation in inflation are different in the two time periods as the propagation mechanisms of various shocks vary because of changes in policy stances. As mentioned above, post-Volcker, low frequency movement in inflation is explained by changes in the inflation target. The high frequency movement is mostly explained by mark-up shocks, which is also a standard result in the literature. In the pre-Volcker period, in contrast, the role of mark-up shocks gets reduced in the short-run while that of technology and demand shocks increases. Moreover, demand and technology shocks also explain much of the variation in the long-run along with a non-trivial role for mark-up shocks. In particular, since monetary policy regime was passive in the pre-Volcker period, demand shocks that would typically be stabilized under active monetary policy end up influencing inflation dynamics significantly.

Sixth, in a counterfactual exercise, we show that had the monetary policy regime of the post-Volcker era been in place pre-Volcker, inflation volatility would have been significantly lower: the predicted standard deviation of inflation is 1.62% compared to the actual value of 2.72%. Moreover, the persistent rise of inflation in the 1970s would not have occurred. Therefore, a different systematic response of monetary policy to inflation would have significantly altered inflation dynamics in the pre-Volcker period.\footnote{Our results are thus consistent with the "good policy" hypothesis that there was a difference in monetary}
2 Model

Our model is based on the prototypical New Keynesian set-up in Woodford (2003). We consider a relatively small-scale model in order to facilitate direct comparisons with earlier influential studies that have addressed related questions in such a framework.\textsuperscript{15} Moreover, doing so also enables us to highlight the precise contribution to our results of the novel feature of our paper, a joint analysis of monetary and fiscal policy effects while allowing for indeterminacy. We nevertheless make certain extensions to the basic textbook set-up that are crucial for the issues that our paper intends to address.

We include external habit formation in consumption, partial dynamic indexation in price setting, and a time-varying inflation target in the monetary policy rule, following the recent DSGE literature. We add these features because not only do they generate inertia and help capture low-frequency movements of the data, but also as emphasized by Lubik and Schorfheide (2004), they help avoid biasing our conclusion towards indeterminacy since the model can generate fairly rich dynamics. Introducing time-varying inflation target in our framework has an additional important benefit as it allows us to disentangle better two competing hypotheses on the rise in inflation in the pre-Volcker period: raised inflation target (Sargent (1999) and Cogley, Primiceri, and Sargent (2010)) as opposed to a weak response of interest rates to inflation and indeterminacy (Clarida, Gali, and Gertler (2000) and Lubik and Schorfheide (2004)).

We add to this set-up an explicit description of fiscal policy.\textsuperscript{16} The government in our model issues one-period nominal risk-less bonds and levies lump-sum taxes to finance interest payments, spending, and exogenous lump-sum transfers. Similar to monetary policy, we posit an endogenous feedback rule for taxes and government spending.

2.1 Households

There is a continuum of households in the unit interval. Each household specializes in the supply of a particular type of labor. A household that supplies labor of type-\( j \) maximizes the utility function:

\[
E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \delta_t \left[ \log \left( C_t^j - \eta C_{t-1} \right) - \frac{\left( H_t^j \right)^{1+\varphi}}{1 + \varphi} \right] \right\},
\]

\textsuperscript{15}See the papers discussed above such as Lubik and Schorfheide (2004), Ireland (2007), and Cogley, Primiceri, and Sargent (2010).

\textsuperscript{16}Kim (2003) introduces monetary and fiscal policy interactions in a calibrated simple New Keynesian model and studies how the propagation mechanism of some shocks differs according to the policy regime.
where $C^j_t$ is consumption of household $j$, $C_t$ is aggregate consumption, and $H^j_t$ denotes the hours of type-$j$ labor services. The parameters $\beta$, $\varphi$, and $\eta$ are, respectively, the discount factor, the inverse of the (Frisch) elasticity of labor supply, and the degree of external habit formation, while $\delta_t$ represents an intertemporal preference shock that follows:

$$\delta_t = \delta^\delta_{t-1} \exp(\varepsilon_{\delta,t}),$$

where $\varepsilon_{\delta,t} \sim$ i.i.d. $N(0, \sigma^2_{\delta})$.

Household $j$’s flow budget constraint is:

$$P_tC^j_t + B^j_t + E_t [Q_{t,t+1}V^j_{t+1}] = W_t(j)H^j_t + V^j_t + R_{t-1}B^j_{t-1} + \Pi_t + S_t - T_t,$$

where $P_t$ is the price level, $B^j_t$ is the amount of one-period risk-less nominal government bond held by household $j$, $R_t$ is the interest rate on the bond, $W_t(j)$ is the competitive nominal wage rate for type-$j$ labor, $\Pi_t$ denotes profits of intermediate firms, and $(S_t - T_t)$ denotes government transfers net of taxes.\(^\text{17}\) In addition to the government bond, households trade at time $t$ one-period state-contingent nominal securities $V^j_{t+1}$ at price $Q_{t,t+1}$, and hence fully insure against idiosyncratic risk.

### 2.2 Firms

The final good $Y_t$, which is consumed by the government and households, is produced by perfectly competitive firms assembling intermediate goods, $Y_t(i)$, with a Dixit and Stiglitz (1977) production technology $Y_t = \left( \int_0^1 Y_t(i) \theta_t^{-1} di \right)^{\frac{1}{\theta_t}}$, where $\theta_t$ denotes time-varying elasticity of substitution between intermediate goods that follows $\theta_t = \bar{\theta}^{1-\theta_t} \theta_t \exp(\varepsilon_{\theta,t})$.\(^\text{18}\) The corresponding price index for the final consumption good is $P_t = \left( \int_0^1 P_t(i)^{1-\theta_t} di \right)^{\frac{1}{1-\theta_t}}$, where $P_t(i)$ is the price of the intermediate good $i$. The optimal demand for $Y_t(i)$ is given by $Y_t(i) = (P_t(i)/P_t)^{-\theta_t} Y_t$.

Monopolistically competitive firms produce intermediate goods using the production function:

$$Y_t(i) = A_t H_t(i),$$

where $H_t(i)$ denotes the hours of type-$i$ labor employed by firm $i$ and $A_t$ represents exogenous economy-wide technological progress. The gross growth rate of technology $a_t \equiv A_t/A_{t-1}$

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\(^\text{17}\)The budget constraint reflects our assumptions that each household owns an equal share of all intermediate firms and receives the same amount of net lump-sum transfers from the government.

\(^\text{18}\)\(\bar{\theta}\) is the steady-state value of $\theta_t$. 

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follows:

\[ a_t = \bar{a}^{1-\rho_a} a_{t-1}^\rho \exp(\varepsilon_{a,t}), \]

where \( \bar{a} \) is the steady-state value of \( a_t \) and \( \varepsilon_{a,t} \sim \text{i.i.d. } N(0, \sigma_a^2) \).

As in Calvo (1983), a firm resets its price optimally with probability \( 1 - \alpha \) every period. Firms that do not optimize adjust their price according to the simple partial dynamic indexation rule:

\[ P_t(i) = P_{t-1}(i) \pi_{t-1}^\gamma \bar{\pi}^{1-\gamma}, \]

where \( \gamma \) measures the extent of indexation and \( \bar{\pi} \) is the steady-state value of the gross inflation rate \( \pi_t \equiv P_t/P_t-1 \).\(^{19}\) All optimizing firms choose a common price \( \bar{P}_t \) to maximize the present discounted value of future profits:

\[ E_t \sum_{k=0}^{\infty} \alpha^k Q_{t,t+k} \left[ \bar{P}_t^* X_{t,k} - \frac{W_{t+k}(i)}{A_{t+k}} \right] Y_{t+k}(i), \]

where

\[ X_{t,k} = \begin{cases} \left( \pi_t \pi_{t+1} \cdots \pi_{t+k-1} \right)^{\gamma} \bar{\pi}^{(1-\gamma)k}, & k \geq 1 \\ 1, & k = 0 \end{cases}. \]

2.3 Government

2.3.1 Budget constraint

Each period, the government collects lump-sum tax revenues \( T_t \) and issues one-period nominal bonds \( B_t \) to finance its consumption \( G_t \), lump-sum transfer payments \( S_t \), and interest payments.\(^{20}\) Accordingly, the flow budget constraint is given by:

\[ \frac{B_t}{P_t} = R_{t-1} \frac{B_{t-1}}{P_t} + G_t - (T_t - S_t), \]

which can be rewritten by expressing fiscal variables as ratios to output:

\[ b_t = R_{t-1} b_{t-1} \frac{1}{\pi_t} \frac{Y_{t-1}}{Y_t} + g_t - \tau_t + s_t, \]

\(^{19}\)Coibion and Gorodnichenko (2011) show that under non-zero steady-state inflation and non-indexation of prices that do not adjust, the indeterminacy region of a model like ours expands substantially relative to the "Taylor principle" while also depending on the level of steady-state inflation. In our model, with the partial dynamic indexation rule specification, this issue does not arise and the long-run response of interest rates to inflation is still the relevant condition for determinacy.

\(^{20}\)In future work, we could relax the restriction of one-period government bonds by allowing for long term debt as in Cochrane (2001). This will reduce inflation volatility under a passive monetary and active fiscal policy regime.
where \( b_t = B_t / P_t Y_t \), \( g_t = G_t / Y_t \), \( \tau_t = T_t / Y_t \), and \( s_t = S_t / Y_t \).

### 2.3.2 Monetary policy

The central bank sets the nominal interest rate according to a Taylor-type rule:

\[
\frac{R_t}{R} = \left( \frac{R_{t-1}}{R} \right)^{\rho_R} \left[ \frac{\phi_{\pi}}{\phi_{\pi}} \left( \frac{Y_t}{Y_t^*} \right) \right]^{1-\rho_R} \exp \left( \varepsilon_{R,t} \right),
\]

which features interest rate smoothing and systematic responses to deviation of output from its natural level \( Y_t^* \) and deviation of inflation from a time-varying target \( \pi_t^* \).\(^{21}\) The steady-state value of \( R_t \) is \( \bar{R} \) and the non-systematic monetary policy shock \( \varepsilon_{R,t} \) is assumed to follow i.i.d. \( N(0, \sigma_R^2) \). The inflation target evolves exogenously as:

\[
\pi_t^* = \pi_{t-1}^{\rho_{\pi}} \exp(\varepsilon_{\pi,t}),
\]

where \( \varepsilon_{\pi,t} \sim \text{i.i.d.} \ N(0, \sigma_{\pi}^2) \).

### 2.3.3 Fiscal policy

We assume parsimonious fiscal policy rules that somewhat resemble the interest rate rule (1).\(^{22}\) The fiscal authority sets its two fiscal policy instruments – tax revenues and government spending – according to the fiscal rules:

\[
\frac{\tau_t}{\bar{\tau}} = \left( \frac{\tau_{t-1}}{\bar{\tau}} \right)^{\rho_{\tau}} \left[ \frac{b_{t-1}}{b_{t-1}^*} \left( \frac{Y_t}{Y_t^*} \right) \right]^{1-\rho_{\tau}} \exp \left( \varepsilon_{\tau,t} \right),
\]

\[
\frac{g_t}{\bar{g}} = \left( \frac{g_{t-1}}{\bar{g}} \right)^{\rho_g} \left( \frac{Y_{t-1}}{Y_{t-1}^*} \right)^{-\bar{\chi}Y(1-\rho_g)} \exp \left( \varepsilon_{g,t} \right).
\]

\(^{21}\)The natural level of output is the output that would prevail under flexible prices and in the absence of shocks to \( \theta_t \).

\(^{22}\)The monetary policy specification is standard, although some extended versions of (1) are often employed in the DSGE literature. The specification of the tax rule is similar to that in Davig and Leeper (2007b), Davig and Leeper (2011), and Sims (2011). While some recent studies consider more elaborate fiscal rules with realistic empirical features – for example, Leeper, Plante and Traum (2010) model different types of distortionary taxes separately rather than an aggregate measure of tax revenues – we focus on a simple specification to keep the model relatively standard. It will be interesting to investigate if new results emerge when the model is extended in various dimensions regarding the specifications of monetary and fiscal policy. In a robustness exercise, we consider some alternative specifications that are relatively straightforward to incorporate in our current framework. We leave more involved extensions that would substantially alter our framework as a future research project.
Fiscal rule (2) features tax smoothing and systematic responses of tax revenues-to-output ratio to deviation of lagged debt-to-output ratio from a time varying target $b_{t-1}$ and deviation of output from its natural level. The steady-state value of $\tau_t$ is $\bar{\tau}$ and the non-systematic tax policy shock $\varepsilon_{\tau,t}$ is assumed to follow i.i.d. $N(0, \sigma_{\tau}^2)$. Similarly to the inflation target, the debt-to-output ratio target evolves exogenously as:

$$b_t^* = (1 - \rho_b) \bar{b} + \rho_b b_{t-1}^* + \varepsilon_{b,t},$$

where $\bar{b}$ is the steady-state value of $b_t$ and $\varepsilon_{b,t} \sim$ i.i.d. $N(0, \sigma_b^2)$. Fiscal rule (3) – motivated by empirical findings of Cúrdia and Reis (2010) – features government consumption smoothing and (potentially) counter-cyclical responses of government spending-to-output ratio to the lagged output gap. The steady-state value of $g_t$ is $\bar{g}$ and the exogenous shock to government spending $\varepsilon_{g,t}$ follows i.i.d. $N(0, \sigma_g^2)$.

Finally, government transfers follow an exogenous process given by:

$$s_t = (1 - \rho_s) \bar{s} + \rho_s s_{t-1} + \varepsilon_{s,t},$$

where $\bar{s}$ is the steady-state value of $s_t$ and $\varepsilon_{s,t} \sim$ i.i.d. $N(0, \sigma_s^2)$.

### 2.4 Equilibrium, policy regimes, and determinacy

Equilibrium is characterized by the prices and quantities that satisfy the households’ and firms’ optimality conditions, the government budget constraint, monetary and fiscal policy rules, and the clearing conditions for the product, labor, and asset markets:

$$\int_0^1 C^j_t dj + G_t = Y_t, \quad H^j_t(j) = H^t_j, \quad \int_0^1 V^j_t dj = 0, \text{ and } \int_0^1 B^j_t dj = B_t.$$

Note that $C^j_t = C_t$ due to the complete market assumption. The details of the optimality conditions and the equilibrium are provided in the Appendix.

We use approximation methods to solve for equilibrium: we detrend variables on the balanced growth path by normalizing by $A_t$ and obtain a first-order approximation to the equilibrium conditions around the non-stochastic steady state. We denote variable $X_t$ by $\tilde{X}_t$. We define the log deviation of a variable $X_t$ from its steady state $\bar{X}$ as

$$\tilde{X}_t = \ln X_t - \ln \bar{X},$$

except for the four fiscal variables: $\tilde{b}_t = b_t - \bar{b}$, $\tilde{g}_t = g_t - \bar{g}$, $\tilde{\tau}_t = \tau_t - \bar{\tau}$, and $\tilde{s}_t = s_t - \bar{s}$.

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23 In Bhattarai, Lee, and Park (2012a) we used a simple specification where government spending followed an exogenous process.

24 We denote variable $X_t$ by $\tilde{X}_t$. We define the log deviation of a variable $X_t$ from its steady state $\bar{X}$ as $\tilde{X}_t = \ln X_t - \ln \bar{X}$, except for the four fiscal variables: $\tilde{b}_t = b_t - \bar{b}$, $\tilde{g}_t = g_t - \bar{g}$, $\tilde{\tau}_t = \tau_t - \bar{\tau}$, and $\tilde{s}_t = s_t - \bar{s}$. 

11
regimes:

\[
\begin{align*}
\hat{R}_t &= \rho_R \hat{R}_{t-1} + (1 - \rho_R) \left[ \phi_{\pi} (\hat{\pi}_t - \hat{\pi}_t^*) + \phi_Y \left( \hat{Y}_t - \hat{Y}_t^* \right) \right] + \varepsilon_{R,t}, \\
\hat{\tau}_t &= \rho_\tau \hat{\tau}_{t-1} + (1 - \rho_\tau) \left[ \psi_b \left( \hat{b}_{t-1} - \hat{b}_{t-1}^* \right) + \psi_Y \left( \hat{Y}_t - \hat{Y}_t^* \right) \right] + \varepsilon_{\tau,t}, \\
\hat{g}_t &= \rho_g \hat{g}_{t-1} - (1 - \rho_g) \chi_Y \left( \hat{Y}_{t-1} - \hat{Y}_{t-1}^* \right) + \varepsilon_{g,t}, \\
\hat{b}_t &= \frac{1}{\beta} \hat{b}_{t-1} + \frac{\hat{b}}{\beta} \left( \hat{R}_{t-1} - \hat{\pi}_t - \hat{Y}_t + \hat{Y}_{t-1} - \hat{a}_t \right) + \hat{g}_t - \hat{\pi}_t + \hat{s}_t.
\end{align*}
\]

The equilibrium of the economy will be determinate either if monetary policy is active while fiscal policy is passive (the AMPF regime) or if monetary policy is passive while fiscal policy is active (the PMAF regime). Multiple equilibria exist if both monetary and fiscal policies are passive (the PMPF regime). In our model, monetary policy is active if \( \phi_{\pi} > 1 - \phi_Y \left( \frac{1-\beta}{\alpha} \right) \), where \( \hat{\beta} = \frac{\gamma+\beta}{1+\gamma\beta} \) and \( \hat{\kappa} = \frac{1-\alpha(1-\gamma)}{\alpha(1+\varphi)(1+\gamma\beta)} \left( 1 + \varphi + \chi_Y \frac{\hat{Y}}{1-\beta} \right) \), and fiscal policy is active if \( \psi_b < \frac{1}{\beta} - 1.25 \).

### 3 Empirical analysis

#### 3.1 Method

We solve the system of linearized equations for its state space representation. We apply the solution method for linear rational expectations models of Sims (2002) under determinacy. Under indeterminacy, we use a generalization of this method proposed in Lubik and Schorfheide (2004) which expresses the solution of the model as:

\[
\begin{align*}
z_t = & \Gamma_1^* \left( \theta \right) z_{t-1} + \left\{ \Gamma_{0,\varepsilon}^* \left( \theta \right) + \Gamma_{0,\zeta}^* \left( \theta \right) M \right\} \varepsilon_t + \Gamma_{0,\zeta}^* \left( \theta \right) \zeta_t,
\end{align*}
\]

where \( z_t \) is a vector of model variables, \( \varepsilon_t \) is a vector of fundamental shocks, and \( \zeta_t \) is a vector of sunspot shocks. The coefficient matrices \( \Gamma_1^* \left( \theta \right), \Gamma_{0,\varepsilon}^* \left( \theta \right), \) and \( \Gamma_{0,\zeta}^* \left( \theta \right) \) are functions of the structural model parameters \( \theta \). The matrix \( \Gamma_{0,\zeta}^* \left( \theta \right) = 0 \) under determinacy, but is not zero in general under indeterminacy. Thus indeterminacy introduces additional parameters, given

\[25\text{Note here that as shown in the Appendix, the relationships between the feedback parameters of the nonlinear and linearized fiscal policy rules are given by: } \psi_b = \frac{\kappa}{\gamma} \psi_b, \psi_Y = \frac{\kappa}{\gamma} \psi_Y, \text{ and } \chi_Y = \frac{\kappa}{\gamma} \chi_Y. \text{ In addition to the boundary conditions described above, we take into account the possibility of an unstable solution due to the endogenous response of government spending to the output gap, which can happen when } \chi_Y \text{ is large enough given the values of other parameters. We rule out such an explosive solution by restricting the parameter space. Also, a set of the parameter values that imply a negative slope of the Phillips curve due to the endogenous government spending is discarded.} \]
by the matrix $M$ in (4), and a sunspot shock.$^{26}$

With a distributional assumption on $\zeta_t$ (and $\varepsilon_t$), one can construct the likelihood of the solution of the model using the Kalman filter. We use standard Bayesian methods widely used in the DSGE literature to fit the model to the data.$^{27}$ We conduct several convergence checks of our posterior simulations, the details of which are provided in the Appendix. For model comparison purposes, we estimate marginal likelihoods using the modified harmonic mean estimator by Geweke (1999).

### 3.2 Data

We use six quarterly U.S. data as observables: per-capita output growth, annualized inflation, annualized federal funds rate, tax revenues-to-output ratio, market value of government debt-to-output ratio, and government spending-to-output ratio. A detailed description of the data is in the Appendix. To make our results comparable to the related literature, we estimate the model over two samples: a pre-Volcker sample from 1960:Q1 to 1979:Q2 and a post-Volcker sample from 1982:Q4 to 2008:Q2. In particular, we drop the Volcker disinflation period.

The corresponding measurement equations are given by:

\[
100 \times \Delta \log(\text{Real per capita output}) = \hat{Y}_t - \hat{Y}_{t-1} + \hat{a}_t + a
\]

Annualized inflation (%) = $4\hat{\pi}_t + 4\pi$

Annualized interest rates (%) = $4\hat{R}_t + 4(a + \pi + \mu)$

\[
\text{Nominal tax revenue } \text{Nominal output } (\%) = \hat{\tau}_t + 100\hat{\tau}
\]

\[
\text{Nominal government debt } \text{Nominal output } (\%) = \hat{b}_t + 100\hat{b}
\]

\[
\text{Nominal government purchases } \text{Nominal output } (\%) = \hat{g}_t + 100\hat{g}
\]

where $a \equiv 100(\bar{\alpha} - 1)$, $\pi \equiv 100(\bar{\pi} - 1)$, and $\mu \equiv 100(\beta^{-1} - 1)$.

---

$^{26}$Appendix provides a more detailed discussion of the solution method. Beyer and Farmer (2007) argue that some caution needs to be applied in using the methodology in Lubik and Schorfheide (2004) since one needs to make some assumption about the dynamic structure of the underlying model in distinguishing a determinate equilibrium from an indeterminate one. Lubik and Schorfheide (2007) reply that such identifying assumptions are inherent in any structural econometric work. We align ourselves with the Lubik and Schorfheide (2007) argument. In addition, in the Appendix, we point to a numerical identification problem in the original method of Lubik and Schorfheide (2004) and propose a resolution to it.

$^{27}$We explain details of the Bayesian methods in the Appendix. For a general introduction to Bayesian methods, see An and Schorfheide (2007).
3.3 Prior distributions

We calibrate $\varphi = 1$ and $\bar{\theta} = 8$ since they are not separately identified from $\alpha$. We also calibrate $\rho_{\pi^*}$ and $\rho_{\theta^*}$ to 0.995 in order to restrict the role for time-varying policy targets to that of explaining low frequency behavior of the data only. For all the other parameters that we estimate, the priors we use are in Table 1. For the mean value of observables and the technology growth rate, we use sample specific priors. We use the same priors across the two sample periods for all other parameters. Most of the priors that we use are standard in the literature. We discuss in detail two sets of priors that are unique to our analysis.

The first are those for the two key policy parameters in the monetary and fiscal rules: $\phi_{\pi}$ and $\psi_{b}$. We reparameterize the model by introducing new parameters $\phi_{\pi}^*$ and $\psi_{b}^*$ that measure the distance from the boundary of active and passive policies. Let us denote the boundary for monetary policy and fiscal policy by $M(\phi_{\pi})$ and $F(\psi_{b})$, respectively.

Then let:

$$
\phi_{\pi} = \Phi^M(\theta) + \hat{\phi}_{\pi}^*; \psi_{b} = \Phi^F(\theta) + \hat{\psi}_{b}^*,
$$

$$
\phi_{\pi} = \Phi^M(\theta) - \hat{\phi}_{\pi}^*; \psi_{b} = \Phi^F(\theta) - \hat{\psi}_{b}^*,
$$

$$
\phi_{\pi} = \Phi^M(\theta) - \hat{\phi}_{\pi}^*; \psi_{b} = \Phi^F(\theta) + \hat{\psi}_{b}^*,
$$

for the AMPF, PMAF, and PMPF regimes, respectively. We assume that $\phi_{\pi}^*$ and $\psi_{b}^*$ have a gamma prior distribution whose domain is positive. This reparameterization thus ensures that we completely impose a particular policy regime during estimation.\footnote{Imposing a particular policy regime through this reparameterization makes the posterior density behave well near the boundary of the policies, which leads to stable numerical operations in estimation and good convergence of posterior simulation.} The implied 90% prior probability interval for $\phi_{\pi}$ is $(1.189, 1.811)$ under AM and $(0.185, 0.811)$ under PM while for $\psi_{b}$ it is $(0.003, 0.107)$ under PF and $(-0.102, 0.003)$ under AF (see Table 2).\footnote{These intervals cover the range of values found in the literature, for example, Davig and Leeper (2011). Note that we restrict the parameter space of $\phi_{\pi}^*$ so that $\phi_{\pi}$ is always positive.}

The second are those related to the case of indeterminacy. As mentioned above, indeterminacy introduces additional parameters, given by the matrix $M$ in (4). We try a few alternate specifications for the priors of those parameters. In the first specification, we follow Lubik and Schorfheide (2004) and set the prior mean of the additional parameters in $M$ so that the impact impulse responses of endogenous variables to fundamental shocks are as close as possible across the boundary between the determinacy and indeterminacy region. Our DSGE model however, exhibits very different dynamics under determinacy and indeterminacy because of the monetary and fiscal policy interactions. We thus do not find it very appealing to require that the DSGE model have similar dynamics across the determinacy and indeterminacy
boundary. In the second specification, we therefore set the prior mean of $M$ to zero. Since $\Gamma_{0,l}(\theta)$ and $\Gamma_{0,c}(\theta)$ in (4) are orthogonal, this specification implies that the initial impact of fundamental shocks is orthogonal to that of sunspot shocks at the prior mean. In addition, we employ a quite diffuse prior for $M$ to check the sensitivity of our results. In the remainder of this paper, we report the results based on the second specification. Our results however, are robust across the different specifications.

### 3.4 Model comparison

To compare model fit, we use marginal likelihoods across different policy regime specifications. As Table 3 makes clear, the best-fitting model is the PMPF regime pre-Volcker, which implies indeterminacy, and the AMPF regime post-Volcker.\(^{30}\) In this regard, our finding is in line with Lubik and Schorfheide (2004). As we will show below however, the propagation mechanism under our PMPF regime is substantively different from that under passive monetary policy in their paper. This underscores the importance of an explicit specification of both monetary and fiscal policies and the inclusion of fiscal variables in model estimation.\(^{31}\)

Moreover, note that although we estimate the model conditional on one policy regime at a time, it is possible to construct an unconditional posterior distribution of the parameters across all three policy regimes. This requires specifying a prior distribution over the policy regimes and then sampling from the posterior distribution of the parameters conditional on each policy regime, according to the posterior distribution over the policy regimes. However, since the best-fitting policy regime in both time-periods dominates other policy regimes in terms of marginal likelihoods, with any reasonable prior distributions over the policy regimes, the unconditional posterior distribution of the parameters will be almost the same as the posterior distribution of the parameters conditional on the best-fitting policy regime.

\(^{30}\)Computing autocorrelation and cross-correlation functions, we have explored in depth our results on model-fit of the various regimes. The detailed results are available on request from the authors. The model-fit result for the post-Volcker period is standard and conventional for any sub-sample estimation exercise. For the pre-Volcker period, compared to the PMAF regime, the PMPF regime fits better the autocorrelations of inflation and interest rates and the cross-correlations between inflation, interest rates, and debt while compared to the AMPF regime, it fits better the autocorrelation of inflation and the cross-correlations of interest rates and output growth and interest rates and inflation. Also, note that if we had restricted the estimation to determinacy, then PMAF fits the data better than AMPF pre-Volcker. This result is in contrast with that of Traum and Yang (2011a), who use a different model and data. In future, it will be interesting to fully explore the main reasons for this difference. Moreover, Bianchi and Iliut (2012) use a one-time, unanticipated, and permanent regime switch set-up from an PMAF regime to a AMPF regime to explain the rise of inflation in the 1970s. Compared to our split-sample estimation, they find the date of the switch endogenously, but do not conduct a formal model comparison exercise while allowing for indeterminacy.

\(^{31}\)We describe in detail later why the inclusion of fiscal variables in estimation is important in the pre-Volcker period for inference and identification.
3.5 Posterior estimates

In Table 4 we present the posterior estimates of the best fitting models for the two sample periods: PMPF for pre-Volcker and AMPF for post-Volcker. As to be expected, the estimates of some key policy parameters are different: the implied estimate of the posterior mean for $\phi_\pi$ is 0.258 pre-Volcker and 1.348 post-Volcker while for $\psi_b$ it is 0.052 pre-Volcker and 0.096 post-Volcker. The 90% posterior probability interval for $\phi_\pi$ is (0.032, 0.451) pre-Volcker and (0.971, 1.721) post-Volcker while for $\psi_b$ it is (0.012, 0.089) pre-Volcker and (0.031, 0.157) post-Volcker.

In addition to the feedback parameters, we also find that the volatility of the two shocks in the monetary policy rule, $\varepsilon_{\pi,t}$ and $\varepsilon_{R,t}$, changed significantly across the sample periods. The standard deviation of the shock to the inflation target dropped from 0.060 to 0.036 while the volatility of the monetary policy shock fell from 0.174 to 0.108. This finding is in line with that of Cogley, Primiceri, and Sargent (2010), even though our policy regime in the pre-Volcker period is different from theirs and unlike them, we include fiscal variables in our estimation. In contrast to shocks in the monetary policy reaction function, there was no substantial change in the volatility of the two shocks in the fiscal policy rule, $\varepsilon_{b,t}$ and $\varepsilon_{\tau,t}$, after the Volcker disinflation.

With respect to the structural model parameters, we find that the degree of price stickiness increased in the post-Volcker period compared to the pre-Volcker period, while the degree of price indexation declined. These findings are consistent with results from a similar subsample estimation exercise in Smets and Wouters (2007) and also echo those of Benati (2008), who argues that evidence for price indexation is low across many countries during time-periods of a stable monetary policy regime.\footnote{They are also in the spirit of Cogley and Sbordone (2008), who find that once one allows for a time-varying inflation target, there is no need to include indexation in price-setting in sticky-price models.} In addition, the degree of habit formation $\eta$ is lower pre-Volcker than post-Volcker, which again confirms the finding of previous studies such as Smets and Wouters (2007) and Cogley, Primiceri, and Sargent (2010). Our estimate in the pre-Volcker period, 0.232, however, is smaller than those obtained in the previous studies because under PMPF, the model can generate fairly persistent dynamics relative to under AMPF without requiring a high level of habit formation.\footnote{When we imposed AMPF pre-Volcker, the estimate of $\eta$ is 0.750 and not significantly different from the estimate in the post-Volcker period.}

In terms of exogenous processes not related to the policy reaction functions, the standard deviation of most shocks decreased in the post-Volcker compared to the pre-Volcker period. For example, the standard deviation of the cost-push shock $\hat{u}_t$ declined by a quantitatively important amount, which probably reflects less significant oil price shocks in the post-Volcker
The notable exception to this is the demand shock $\hat{d}_t$ which became more volatile in the post-Volcker period. In terms of the persistence parameter, while it decreased for most shocks, it increased quite a bit for the technology shock $\hat{a}_t$ and increased marginally for the government spending shock $\hat{g}_t$.

### 3.6 Propagation of shocks

#### 3.6.1 Transmission mechanism of policy

In Figures 1 – 4 we present impulse responses to monetary and fiscal policy shocks in the two sample periods. Our main finding is that for the best fitting models, PMPF pre-Volcker and AMPF post-Volcker, the monetary and fiscal policy transmission mechanisms are substantially different. Moreover, we find that the monetary and fiscal policy transmission mechanisms in our estimated PMPF model in the pre-Volcker era are similar to those that would prevail under PMAF in important dimensions.

For the best fitting model pre-Volcker, as shown in Figure 1, a monetary contraction (i.e. an unanticipated increase in the nominal interest rate) leads to an increase in output and inflation. Thus our results provide a model based interpretation to the "price puzzle" of the identified VAR literature: the tendency of inflation to increase on impact following a contractionary monetary policy shock. Hanson (2004) in a comprehensive study showed that this "price puzzle" seems to be a feature only of the pre-Volcker period and not for the entire post-War U.S. data, which is consistent with our results. Moreover, this result is in line with the prediction of the FTPL, which would be operative under PMAF if the equilibrium was determinate. FTPL predicts an increase in spending following an interest rate increase due to a positive wealth effect, which then increases output and inflation, as shown in Figure 1.

In addition, pre-Volcker, the impulse responses to various fiscal shocks are also similar to those predicted by the FTPL. For example, an exogenous increase in the lump-sum tax-to-output ratio produces a recession, decreasing output and inflation as shown in Figure 3, an event one would not observe under conventional AMPF. The interest rate decreases as well, as it only weakly responds to lower inflation due to passive monetary policy. This follows the prediction of the FTPL: an increase in taxes leads to a negative wealth effect, which decreases spending and thereby inflation and output. This is shown clearly in Figure 3. We thus find that our estimated best-fitting model pre-Volcker, a PMPF regime, mimics a PMAF regime in important dimensions, even though it is not technically one where the FTPL has to be operative for sure.\(^35\)

\(^34\)Similar to Smets and Wouters (2007), we normalized some shocks. Specifically, we estimated $\hat{d}_t \equiv (1 - \rho_\delta) \hat{\delta}_t$ and $\hat{a}_t \equiv \frac{(1 - \alpha \beta)(1 - \alpha)}{\alpha(1 + \epsilon_\theta\beta)(1 + \gamma_\theta)} \frac{1}{1 - \rho_\theta} \hat{\theta}_t$. See the Appendix for the model equations used in our estimation.

\(^35\)Note that although the PMPF regime mimics the PMAF regime in the aforementioned dimensions, it is
While the pre-Volcker U.S. economy was characterized by PMPF, it was under a AMPF regime post-Volcker. Accordingly, and unlike the pre-Volcker era, the impulse responses are in line with the predictions of standard monetary models: Figure 2 shows that an unanticipated increase in the nominal interest rate leads to a decrease, not an increase, in inflation. In addition, as Figure 4 makes clear, exogenous adjustments in tax revenues do not affect output, inflation, and the interest rate, a conventional Ricardian equivalence result.

Moreover, Figures 2 and 4 show that post-Volcker, the PMPF model also produces quite similar dynamics to AMPF. For example, as shown in Figure 2, the impulse responses to a monetary contraction are quite similar between the two regimes, although the error bands are much wider under PMPF. Similarly, Figure 4 illustrates that the two regimes have similar predictions also for the propagation of fiscal shocks, since an unanticipated increase in tax-to-output ratio has no meaningful impacts on output, inflation and the interest rate while reducing debt-to-output ratio under both the regimes. While the dynamics are similar, since the PMPF regime involves many more estimated parameters, it is not favored over the AMPF regime in our Bayesian model comparison.

We emphasize that our results for the pre-Volcker period are data-driven and not hard-wired into our model specification and estimation. Depending on how self-fulfilling beliefs are formed, as shown above, the model under PMPF can generate a wide range of dynamics, including those that are similar to the outcomes under AMPF or PMAF or neither. With the additional parameters in $M$ and the sunspot shocks, we characterize the full set of indeterminate beliefs and construct their distribution conditional on the data. While doing so, we find, for example, that the pre-Volcker data favors the agents’ beliefs that inflation would increase on impact (and afterwards) in response to a monetary contraction. Under PMPF post-Volcker however, we find that the agents did not believe that inflation would increase in response to interest rate increases. Similarly, the pre-Volcker data favors the agents’ beliefs that inflation would decrease on impact (and afterwards) in response to fiscal contractions. Under PMPF post-Volcker however, our estimates imply that the agents believed that inflation would increase in response to lump-sum tax increases on average. However, since the error band is quite wide and covers zero, the effect is not significant.

To make these mechanisms even more transparent, in Figure 5, we decompose the impulse responses to monetary policy shocks under PMPF in the two time periods into two components as given by (4): the part due to $\Gamma_{0,\varepsilon}^* (\theta)$ (the determined component) and that due to $\Gamma_{0,\xi}^* (\theta) M$ (the undetermined component that captures self-fulfilling beliefs). As is clear, while pre-Volcker, the self-fulfilling beliefs captured by the undetermined component imply an increase in inflation following a monetary contraction, post-Volcker, they imply a

different in other dimensions and thus is well identified.
decrease in inflation. The undetermined component thus plays a decisive role post-Volcker in the overall negative response of inflation to a positive interest rate shock. Similarly, in Figure 6, we decompose the impulse responses to fiscal policy shocks under PMPF in the two time periods into the determined and undetermined components. As is clear, while pre-Volcker, self-fulfilling beliefs captured by the undetermined component imply a decrease in inflation following a fiscal contraction, post-Volcker, they imply an increase in inflation. The undetermined component thus plays a decisive role in both the periods in pinning down the response of inflation to a lump-sum tax shock.

3.6.2 Variance decomposition

Role of random component of policy We showed above that transmission mechanisms of monetary and fiscal policies are substantially different in the two time-periods. We next assess how important were the random components in policies in explaining variations in inflation and output growth. Variance decomposition results, as given in Tables 5 and 6, show that in both the time-periods and at both the short and long-run, unanticipated shifts in monetary and fiscal policies play only a minor role in explaining the dynamics of inflation and output.36

For example, for inflation, pre-Volcker, monetary and fiscal policy shocks explain less than 11% of the variation at both horizons. In particular, pre-Volcker, lump-sum tax shocks explain 2.7% of inflation variation in the short-run and 0.9% in the long-run. These effects, while smaller, are roughly similar to those of monetary policy shocks, which explain 10.7% of inflation variation in the short-run and 5.7% in the long-run. Post-Volcker, while the fiscal policy shock explains no variation at either horizon because the prevailing regime is AMPF, the monetary policy shock also is estimated to explain basically no variation at either horizon.

For output growth, pre-Volcker, monetary policy shocks explain around 1.6% while fiscal policy shocks explain around 4.6% of the variation in both the short and long-run. Post-Volcker, the monetary shock explains around 2.5% of the variation at both horizons while fiscal policy shocks explain basically no variation in output growth. Our result that random variations in monetary policy do not explain much of the fluctuations in inflation and output is consistent with the results in the identified VAR literature, for example, Sims and Zha (2006a). That the same conclusion also holds for random variations in fiscal policy, given by unanticipated movements in taxes, is new, as far as we are aware, to the literature on estimated DSGE models that jointly feature both monetary and fiscal policies.

Role of time-varying inflation target We next assess the role of time-varying inflation target in explaining inflation dynamics, in particular the rise in inflation in the pre-Volcker

36 We focus on a 4 and 40 quarter horizon in our variance decomposition results.
period. In the recent estimated DSGE literature, a consensus finding has emerged that the long-run variation in inflation is explained mostly by shocks to the inflation target in the monetary reaction function. For example, Ireland (2007) and Cogley, Primiceri, and Sargent (2010) show that both pre- and post-Volcker, smoothed values of the inflation target recovered from estimation track actual inflation remarkably well. In contrast, we find that pre-Volcker, as opposed to post-Volcker, variations in the inflation target do not explain low-frequency movements in inflation.

Table 5 clearly shows that while we find a similar result to Cogley, Primiceri, and Sargent (2010) in the post-Volcker period, where the inflation target shock accounts for 82.6% of the long-run variation in inflation, our results are quite different in the pre-Volcker era, where the inflation target shock explains only 10.1% of the long-run variation in inflation. We make this result also clear in Figure 7, which plots smoothed inflation target recovered from the estimation of the model in the two time-periods under various policy regime combinations. While inflation target changes track inflation well under an AMPF regime, this correspondence weakens substantially under either PMPF or PMAF.

The major reason for this difference is that we explicitly allow for the possibility of indeterminacy while estimating our model that features both monetary and fiscal policy. When the regime is active monetary and passive fiscal policy, as is the implicit assumption in Ireland (2007) and Cogley, Primiceri, and Sargent (2010) for both the time-periods, then changes in inflation target do explain inflation in the long-run since monetary policy fully controls inflation dynamics. Our best-fitting estimated model in the pre-Volcker features indeterminacy due to passive monetary policy, however. In this case, consider an increase in the inflation target. This, through the central bank reaction function, does tend to decrease the interest rate. A decrease in interest rate in this model though, as we pointed out above, tends to decrease inflation. Thus, inflation target movements do not track actual inflation in the long-run. Figure 7 thus makes clear how the role of time-varying inflation target in explaining the low-frequency movement in inflation depends crucially on the monetary and fiscal policy regime in place.

**Role of other fundamental shocks** We now address in detail which shocks were major drivers of the dynamics of inflation. Our main finding is that the primary sources of short and long-run variations in inflation are quite different in the two time periods as the propagation mechanism of shocks varies because of the change in monetary policy stances. As mentioned above, and shown clearly in Table 5, post-Volcker, low frequency movement in inflation is explained mostly by changes in the inflation target. The high frequency movement is mostly explained by mark-up shocks, which is also a standard result in the literature. In the pre-Volcker period, in contrast, the role of mark-up shocks gets reduced in the short-run while
that of technology and demand shocks increases. Moreover, demand and technology shocks also explain much of the variation in the long-run along with a non-trivial role for mark-up shocks. The important role of mark-up shocks at both horizons in the pre-Volcker period is not surprising given the oil price shocks of the 1970s. Moreover, in the pre-Volcker period, since the monetary policy regime was passive, demand shocks that would typically be stabilized under active monetary policy end up influencing inflation dynamics significantly. To emphasize this role of demand shocks, in Figure 8 we report results on the implied counterfactual path of inflation in the pre-Volcker period if we simulate our model using smoothed values of all other shocks except demand shocks. As is clear, the rise of inflation in the 1970s is muted in that case.

**Role of sunspot shocks** How important are sunspot shocks in explaining variation in inflation and output growth in the pre-Volcker period? As Tables 5–6 makes clear, sunspot shocks introduced due to indeterminacy play a quite minor role in explaining the dynamics of inflation and output.\(^{37}\) Thus indeterminacy matters in our estimated model, not because of a non-trivial role for sunspot fluctuations, but mostly because self-fulfilling beliefs regarding fundamental shocks significantly alter the propagation mechanisms in the model.

### 3.6.3 Role of policy in the rise of inflation

Having found that neither exogenous variations in the inflation target nor sunspot shocks played a major role in the rise of inflation and its high volatility in the pre-Volcker period, we now evaluate the role of changes in the monetary policy regime. To this end, we conduct a counterfactual exercise assessing the model implied path of various observables had the post-Volcker monetary policy regime been in place in the pre-Volcker period. In particular, with the estimated model parameters and smoothed shocks of the pre-Volcker period, we simulate our model by making two changes: shutting down the shocks \(\hat{\pi}_t\) and \(\varepsilon_{R,t}\) while using the estimate of \(\phi_\pi\) from the post-Volcker period.\(^{38}\)

First, we find that the model implied standard deviation of inflation is 1.62%, which is substantially lower than the actual value of 2.72%. Moreover, Figure 9, where we plot the model implied path of inflation together with actual inflation, makes clear that under this monetary policy regime, the rise of inflation in the 1970s would have been avoided. Thus, our

\(^{37}\)Lubik and Schorfheide (2004) also found a minor role of sunspot shocks.

\(^{38}\)Note here that we only change \(\phi_\pi\) and in particular, keep the fiscal parameters the same as the estimated values. We shut down the exogenous shocks in the monetary policy rule (\(\hat{\pi}_t\) and \(\varepsilon_{R,t}\)), to consider in isolation the effect on inflation dynamics of a change in the systematic response of monetary policy. Shutting them down, however, does not influence our results. In other words, under PMPF in the pre-Volcker regime, inflation dynamics with and without these shocks are virtually identical, as our earlier variance decomposition results make clear.
counterfactual exercise suggests that a change in the systematic response of monetary policy would have mattered greatly for inflation dynamics in the pre-Volcker era. Second, we find that while output growth would not have been quantitatively different, the debt-to-output ratio would have been higher in the 1970s. The higher debt-to-output ratio is a result of lower implied inflation, which negates its role in debt stabilization. Figure 9, where we plot the model implied path of output growth and debt-to-output ratio together with their actual paths, depicts these results clearly.

3.7 Discussion

3.7.1 Role of fiscal policy

We now assess the role played by including fiscal policy explicitly in the model and using fiscal variables as observables in estimation on inference and identification in the pre-Volcker period. It is perhaps easy to see some direct benefits of including fiscal variables in the model and estimation. For example, without it, one would not be able to make a meaningful inference regarding the effects of fiscal policy changes on key aggregate variables such as inflation and output. We have shown that these effects were statistically significant in the pre-Volcker period. Moreover, dropping fiscal policy from the model would preclude the possibility of a PMAF regime, which potentially biases our inference towards indeterminacy. There is however, an additional benefit that is less obvious, and which will be the focus of this subsection. In particular, we illustrate below that including fiscal variables in the model and estimation provides additional information about self-fulfilling beliefs of the agents, which in turn leads to a better identification of the matrix $M$ and more robust inference regarding the propagation of monetary policy shocks under PMPF.

Note that for the post-Volcker period, since our best-fitting regime is AMPF and because taxes and transfers are lump-sum, it is clear that fiscal variables have no effect on inflation and output dynamics.\footnote{\footnotesize Even under active monetary policy, it is not generally the case that estimation results are the same whether or not one includes fiscal variables as observables. This is because of the cross-equation restrictions implied in a general equilibrium model. This difference though is not our focus in this section.} For the pre-Volcker period, our best-fitting regime is PMPF, and one might wonder whether inclusion of fiscal variables makes any substantial difference to our results because while there is indeterminacy, fiscal policy is still passive in this regime. We show below that it is not the case.

As we discussed above, the most striking result in the pre-Volcker period is that unanticipated increases in interest rates lead to an increase in inflation and output on impact and for several periods after, thereby, exhibiting the "price puzzle." In Figure 10 (second row) in the Appendix, we show the estimated effects of monetary policy shocks when we repeat the
estimation of our model under indeterminacy while dropping fiscal policy from the model and fiscal variables from estimation and using our baseline prior on the matrix $M$ (that is, $N(0, 1)$). The results look quite similar to those in Figure 1. This might, perhaps give the impression that fiscal variables do not play a critical role in inference about effects of monetary policy shocks. In Figure 10 (first row) in the Appendix however, we show the results when we repeat this analysis with the same prior on $M$ as in Lubik and Schorfheide (2004). It is now clear that inference regarding the effects of monetary policy shock is different and that the "price puzzle" result is no longer apparent. In fact, now our results look similar to those in Lubik and Schorfheide (2004) since there is neither statistically nor economically significant effect of monetary policy shock on inflation.\footnote{These results are consistent with those of Belaygorod and Dueker (2009), who also found that the results of the exercise in Lubik and Schorfheide (2004) depend on the prior on $M$.} Moreover, we also show results using a diffuse prior on $M$ (that is, $Uniform(-5, 5)$) in Figure 10 (third row), for which the results are similar to the baseline case. Thus, without fiscal variables in the model and estimation, the results of the indeterminate regime are not well identified and robust across different priors on $M$.

In contrast, when we include fiscal variables in the model and estimation for the pre-Volcker period, as we discussed above, our results are robust to what prior we assign to $M$. To make this transparent, in Figure 11 in the Appendix, we show the effects of monetary policy shocks in our model under these three different sets of priors on $M$. It is clear that the results are very similar across different prior specification and that inference regarding the effects of a monetary policy shock is robust.\footnote{In a model with monetary and fiscal policy interactions, under PMPF, $M_R\epsilon$ influences the impact of monetary policy shocks on not only output, inflation, and the interest rate but also, fiscal variables. Therefore, using data on fiscal variables can provide an additional source of identification.} We therefore conclude that fiscal variables are important to include in estimation of monetary DSGE models in the pre-Volcker period because they help in identification by capturing self-fulfilling beliefs on propagation of monetary shocks.

### 3.7.2 Robustness

We conduct three major robustness exercises.\footnote{All the results from this section are available on request from the authors.} First, as emphasized by Sims and Zha (2006b), we include a monetary aggregate in the monetary policy reaction function. We implement this extension because Sims and Zha (2006b) argue that inclusion of monetary aggregates in the central bank’s reaction function is a more accurate description of monetary policy in the pre-Volcker era and that moreover, doing so helps guard against inference in favor of indeterminacy in that period. In this specification, we introduce money in the model using a standard money-in-utility specification and allow for a money demand shock. We then use additional data on inverse velocity while estimating the model. Second, we estimate the model without time-varying inflation and debt targets. We do this exercise primarily because we find a negligible
role for a time-varying debt target in both the periods and a time-varying inflation target in the pre-Volcker period. Third, we estimate the model with a ARMA specification for the shocks. We conduct this exercise to assess whether allowing for a more flexible shock specification can reverse our finding of indeterminacy in the pre-Volcker period. These alternate specifications do not affect the substantive results of our paper. The best-fitting models are still PMPF pre-Volcker and AMPF post-Volcker. Moreover, the impulse responses to monetary and fiscal policy shocks in the best-fitting models are remarkably similar to the baseline case.

4 Conclusion

In this paper we have addressed some long-standing questions in macroeconomics using an estimated DSGE model that has an explicit description of both monetary and fiscal policies. Our main result is that the monetary and fiscal policy regime combination in place has mattered historically for a host of issues: the prevalence of equilibrium indeterminacy, the transmission mechanism of monetary and fiscal policy, and the major sources of variation in inflation. That is, we find the nature of the systematic response of policy to the state of the economy to be paramount in the propagation mechanism of both policy and non-policy shocks.

In future research projects, we plan to extend and build on our current work on three fronts. First, we can conduct our analysis using a medium-scale DSGE model such as the one in Smets and Wouters (2007), Del Negro et al (2007), and Justiniano, Primiceri, and Tambalotti (2010). Second, we can allow for time-varying volatility of shocks in our estimated DSGE model, along the lines of Justiniano and Primiceri (2008). Third, as a substantial extension, we can estimate a DSGE model with recurring regime switching in both monetary and fiscal policies, building on the methodology provided in Farmer, Waggoner, and Zha (2011). Another related approach we can adopt is the time-varying policy parameters set-up in Inoue and Rossi (2011) or Fernandez-Villaverde, Guerron-Quintana, and Rubio-Ramirez (2010).

References


43 Davig and Leeper (2007a) is an alternate approach.


Figure 1: Impulse responses to monetary policy shocks in the pre-Volcker period

Note: Figure plots pointwise posterior means (solid lines) and 90-percent probability intervals (dashed lines) for impulse responses to a one standard deviation shock to $e_{R,t}$. Row (a) presents results of the PMAF regime, pre-Volcker, and row (b) presents results of the PMPF regime, pre-Volcker. The unit of the impulse responses is percentage deviations from the steady state for output and percentage point deviations from the steady state for the rest of the variables.
Figure 2: Impulse responses to monetary policy shocks in the post-Volcker period

Note: Figure plots pointwise posterior means (solid lines) and 90-percent probability intervals (dashed lines) for impulse responses to a one standard deviation shock to \( \varepsilon_{R,t} \). Row (a) presents results of the AMPF regime, post-Volcker, and row (b) presents results of the PMPF regime, post-Volcker. The unit of the impulse responses is percentage deviations from the steady state for output and percentage point deviations from the steady state for the rest of the variables.
Figure 3: Impulse responses to fiscal policy shocks in the pre-Volcker period

*Note:* Figure plots pointwise posterior means (solid lines) and 90-percent probability intervals (dashed lines) for impulse responses to a one standard deviation shock to $\varepsilon_{t,t}$. Row (a) presents results of the PMAF regime, pre-Volcker, and row (b) presents results of the PMPF regime, pre-Volcker. The unit of the impulse responses is percentage deviations from the steady state for output and percentage point deviations from the steady state for the rest of the variables.
Figure 4: Impulse responses to fiscal policy shocks in the post-Volcker period

Note: Figure plots pointwise posterior means (solid lines) and 90-percent probability intervals (dashed lines) for impulse responses to a one standard deviation shock to $\varepsilon_{t-1}$. Row (a) presents results of the AMPF regime, post-Volcker, and row (b) presents results of the PMPF regime, post-Volcker. The unit of the impulse responses is percentage deviations from the steady state for output and percentage point deviations from the steady state for the rest of the variables.
Figure 5: Decomposition of the impulse responses to monetary policy shocks

Note: Figure presents three impulse responses of each variable to one standard deviation shock to $\varepsilon_{R,t}$: 1) impulse responses due to the determined part of initial impact of monetary policy shock, 2) impulse responses due to the undetermined part of initial impact of monetary policy shock, and 3) the combined impulse responses of 1) and 2). Row (a) presents the impulse responses under PMPF, pre-Volcker and row (b) presents the impulse responses under PMPF, post-Volcker. The impulse responses were computed at the posterior mode.
Figure 6: Decomposition of the impulse responses to fiscal policy shocks

Note: Figure presents three impulse responses of each variable to one standard deviation shock to $\varepsilon_{t,\lambda}$: 1) impulse responses due to the determined part of initial impact of fiscal policy shock, 2) impulse responses due to the undetermined part of initial impact of fiscal policy shock, and 3) the combined impulse responses of 1) and 2). Row (a) presents the impulse responses under PMPF, pre-Volcker and row (b) presents the impulse responses under PMPF, post-Volcker. The impulse responses were computed at the posterior mode.
### Table 1: Inflation and Inflation Target

<table>
<thead>
<tr>
<th>Year</th>
<th>Percent (annualized)</th>
<th>Inflation target (AMPF)</th>
<th>Inflation target (PMAF)</th>
<th>Inflation target (PMPF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>-5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1965</td>
<td>0</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1970</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1975</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1980</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1985</td>
<td>20</td>
<td></td>
<td></td>
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<td>1990</td>
<td>25</td>
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<tr>
<td>1995</td>
<td>30</td>
<td></td>
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<tr>
<td>2000</td>
<td>35</td>
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</tr>
<tr>
<td>2005</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note: Figure presents actual inflation and the point-wise mean of the smoothed values of the inflation target for the three policy regimes for both the pre- and the post-Volcker periods.*

### Figure 8: Counterfactual path of inflation with no preference shocks

*Note: Figure presents actual and counterfactual path of inflation with the preference shock shut down in the pre-Volcker period under PMPF. The presented counterfactual paths are point-wise mean of counterfactual paths.*
Figure 9: Counterfactual path of output growth, inflation, and debt-to-output ratio

Note: Figure presents actual and counterfactual path of the three variables. The distribution of counterfactual paths was first computed by changing the posterior draws of $\phi^*_\pi$ in the PMPF model pre-Volcker so that $\phi_\pi$ is set to 1.2991, the posterior mean of $\phi_\pi$ in the AMPF model post-Volcker. The presented counterfactual paths are point-wise mean of these counterfactual paths. The monetary policy shock and the inflation target shock were shut down.
Table 1: Prior distribution of structural parameters

<table>
<thead>
<tr>
<th></th>
<th>Pre-Volcker</th>
<th>Post-Volcker</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Distribution</td>
<td>Mean</td>
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<tr>
<td>$\phi_x$</td>
<td>Gamma</td>
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</tr>
<tr>
<td>$\phi_Y$</td>
<td>Gamma</td>
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</tr>
<tr>
<td>$\psi_b$</td>
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<td>$\psi_Y$</td>
<td>Normal</td>
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<tr>
<td>$\chi_Y$</td>
<td>Normal</td>
<td>0.4</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Beta</td>
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</tr>
<tr>
<td>$\eta$</td>
<td>Beta</td>
<td>0.6</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>Beta</td>
<td>0.6</td>
</tr>
<tr>
<td>$\rho_b$</td>
<td>Beta</td>
<td>0.6</td>
</tr>
<tr>
<td>$\rho_a$</td>
<td>Beta</td>
<td>0.6</td>
</tr>
<tr>
<td>$\rho_u$</td>
<td>Beta</td>
<td>0.6</td>
</tr>
<tr>
<td>$\rho_s$</td>
<td>Beta</td>
<td>0.6</td>
</tr>
<tr>
<td>$\rho_R$</td>
<td>Beta</td>
<td>0.6</td>
</tr>
<tr>
<td>$\rho_x$</td>
<td>Beta</td>
<td>0.6</td>
</tr>
<tr>
<td>$\sigma_g$</td>
<td>Inv. Gamma</td>
<td>0.5</td>
</tr>
<tr>
<td>$\sigma_d$</td>
<td>Inv. Gamma</td>
<td>0.5</td>
</tr>
<tr>
<td>$\sigma_a$</td>
<td>Inv. Gamma</td>
<td>0.5</td>
</tr>
<tr>
<td>$\sigma_u$</td>
<td>Inv. Gamma</td>
<td>0.5</td>
</tr>
<tr>
<td>$\sigma_s$</td>
<td>Inv. Gamma</td>
<td>0.5</td>
</tr>
<tr>
<td>$\sigma_R$</td>
<td>Inv. Gamma</td>
<td>0.5</td>
</tr>
<tr>
<td>$\sigma_\tau$</td>
<td>Inv. Gamma</td>
<td>0.5</td>
</tr>
<tr>
<td>$\sigma_\pi$</td>
<td>Inv. Gamma</td>
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</tr>
<tr>
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<td>$\bar{a} - 1$</td>
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</tr>
<tr>
<td>$\bar{\pi} - 1$</td>
<td>Gamma</td>
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</tr>
<tr>
<td>$100(\beta^{-1} - 1)$</td>
<td>Gamma</td>
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</tr>
<tr>
<td>$100\hat{\theta}$</td>
<td>Normal</td>
<td>36</td>
</tr>
<tr>
<td>$100\tilde{\gamma}$</td>
<td>Gamma</td>
<td>25</td>
</tr>
</tbody>
</table>

Additional parameters under indeterminacy

| $\sigma_\zeta$ | Inv. Gamma | 0.5  | 2        | [0.166, 1.237] |
| $M_{g\zeta}$   | Normal     | 0    | 1        | [-1.645, 1.645] |
| $M_{d\zeta}$   | Normal     | 0    | 1        | [-1.645, 1.645] |
| $M_{u\zeta}$   | Normal     | 0    | 1        | [-1.645, 1.645] |
| $M_{s\zeta}$   | Normal     | 0    | 1        | [-1.645, 1.645] |
| $M_{R\zeta}$   | Normal     | 0    | 1        | [-1.645, 1.645] |
| $M_{r\zeta}$   | Normal     | 0    | 1        | [-1.645, 1.645] |
| $M_{\pi\zeta}$ | Normal     | 0    | 1        | [-1.645, 1.645] |
| $M_{b\zeta}$   | Normal     | 0    | 1        | [-1.645, 1.645] |

Note: The column labeled [5th, 95th] presents the 5th and 95th percentiles. The parameters $M_{g\zeta}, M_{d\zeta}, \ldots$, $M_{b\zeta}$ are entries of $M$ in (4).
Table 2: Prior distribution of monetary and fiscal policy parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Policy</th>
<th>Mean</th>
<th>St. Dev.</th>
<th>5th, 95th</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi_\pi$</td>
<td>Active Monetary</td>
<td>1.500</td>
<td>0.200</td>
<td>[1.189, 1.811]</td>
</tr>
<tr>
<td></td>
<td>Passive Monetary</td>
<td>0.497</td>
<td>0.200</td>
<td>[0.185, 0.811]</td>
</tr>
<tr>
<td>$\psi_b$</td>
<td>Active Fiscal</td>
<td>-0.047</td>
<td>0.040</td>
<td>[-0.102, 0.003]</td>
</tr>
<tr>
<td></td>
<td>Passive Fiscal</td>
<td>0.053</td>
<td>0.040</td>
<td>[0.003, 0.107]</td>
</tr>
</tbody>
</table>

Note: The last column presents the 5th and 95th percentiles. The prior distribution of $\phi_\pi$ and $\psi_b$ was obtained based on a simulation from the prior distribution of the structural parameters. Since the prior distribution of those parameters that determine the boundary condition of active and passive policy is identical pre-Volcker and post-Volcker, $\phi_\pi$ and $\psi_b$ also have the same prior distribution across the subsamples.

Table 3: Comparison of the marginal likelihood of alternate regimes

<table>
<thead>
<tr>
<th></th>
<th>Determinacy</th>
<th>Indeterminacy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AMPF</td>
<td>PMAF</td>
</tr>
<tr>
<td>Pre-Volcker</td>
<td>-541.7</td>
<td>-537.4</td>
</tr>
<tr>
<td>Post-Volcker</td>
<td>-553.2</td>
<td>-564.1</td>
</tr>
</tbody>
</table>

Note: Table reports log marginal likelihoods that are computed using the harmonic mean estimator proposed by John F. Geweke (1999).
Table 4: Posterior distribution of structural parameters

<table>
<thead>
<tr>
<th></th>
<th>Pre-Volcker (PMPF)</th>
<th>Post-Volcker (AMPF)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean [5th, 95th]</td>
<td>Mean [5th, 95th]</td>
</tr>
<tr>
<td>$\phi_\tau^*$</td>
<td>0.734 [0.546, 0.960]</td>
<td>0.478 [0.188, 0.753]</td>
</tr>
<tr>
<td>$\phi_\eta$</td>
<td>0.258 [0.032, 0.451]</td>
<td>1.348 [0.971, 1.721]</td>
</tr>
<tr>
<td>$\phi_Y$</td>
<td>0.292 [0.183, 0.403]</td>
<td>0.438 [0.301, 0.571]</td>
</tr>
<tr>
<td>$\psi_b^*$</td>
<td>0.050 [0.010, 0.087]</td>
<td>0.094 [0.028, 0.154]</td>
</tr>
<tr>
<td>$\psi_b$</td>
<td>0.052 [0.012, 0.089]</td>
<td>0.096 [0.031, 0.157]</td>
</tr>
<tr>
<td>$\psi_Y$</td>
<td>0.743 [0.495, 0.991]</td>
<td>0.817 [0.450, 1.176]</td>
</tr>
<tr>
<td>$\chi_Y$</td>
<td>0.366 [-0.112, 0.829]</td>
<td>0.239 [-0.278, 0.757]</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.671 [0.547, 0.796]</td>
<td>0.836 [0.776, 0.898]</td>
</tr>
<tr>
<td>$\eta$</td>
<td>0.232 [0.065, 0.383]</td>
<td>0.731 [0.610, 0.855]</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>0.339 [0.054, 0.622]</td>
<td>0.141 [0.027, 0.248]</td>
</tr>
<tr>
<td>$\rho_\delta$</td>
<td>0.966 [0.943, 0.992]</td>
<td>0.987 [0.977, 0.997]</td>
</tr>
<tr>
<td>$\rho_\delta$</td>
<td>0.865 [0.766, 0.966]</td>
<td>0.859 [0.777, 0.944]</td>
</tr>
<tr>
<td>$\rho_a$</td>
<td>0.352 [0.054, 0.645]</td>
<td>0.524 [0.235, 0.819]</td>
</tr>
<tr>
<td>$\rho_\theta$</td>
<td>0.376 [0.075, 0.658]</td>
<td>0.122 [0.026, 0.216]</td>
</tr>
<tr>
<td>$\rho_s$</td>
<td>0.752 [0.612, 0.894]</td>
<td>0.743 [0.634, 0.852]</td>
</tr>
<tr>
<td>$\rho_R$</td>
<td>0.678 [0.536, 0.812]</td>
<td>0.804 [0.747, 0.860]</td>
</tr>
<tr>
<td>$\rho_\tau$</td>
<td>0.478 [0.285, 0.665]</td>
<td>0.842 [0.774, 0.915]</td>
</tr>
<tr>
<td>$\sigma_d$</td>
<td>0.227 [0.196, 0.257]</td>
<td>0.164 [0.145, 0.183]</td>
</tr>
<tr>
<td>$\sigma_a$</td>
<td>0.275 [0.170, 0.374]</td>
<td>0.495 [0.213, 0.796]</td>
</tr>
<tr>
<td>$\sigma_m$</td>
<td>0.524 [0.210, 0.804]</td>
<td>0.417 [0.169, 0.661]</td>
</tr>
<tr>
<td>$\sigma_u$</td>
<td>0.206 [0.153, 0.257]</td>
<td>0.142 [0.120, 0.163]</td>
</tr>
<tr>
<td>$\sigma_s$</td>
<td>1.020 [0.883, 1.15]</td>
<td>1.364 [1.208, 1.522]</td>
</tr>
<tr>
<td>$\sigma_R$</td>
<td>0.174 [0.142, 0.205]</td>
<td>0.108 [0.093, 0.123]</td>
</tr>
<tr>
<td>$\sigma_\tau$</td>
<td>0.617 [0.508, 0.725]</td>
<td>0.573 [0.502, 0.641]</td>
</tr>
<tr>
<td>$\sigma_b$</td>
<td>0.060 [0.027, 0.093]</td>
<td>0.036 [0.024, 0.048]</td>
</tr>
<tr>
<td>$\sigma_\xi$</td>
<td>0.349 [0.169, 0.522]</td>
<td>0.396 [0.173, 0.618]</td>
</tr>
<tr>
<td>$\rho_\delta + 1$</td>
<td>1.055 [0.902, 1.208]</td>
<td>0.643 [0.481, 0.801]</td>
</tr>
<tr>
<td>$\rho_\delta$</td>
<td>0.159 [0.058, 0.258]</td>
<td>0.229 [0.091, 0.358]</td>
</tr>
<tr>
<td>$\rho_\delta$</td>
<td>36.455 [33.171, 39.768]</td>
<td>48.235 [44.955, 51.447]</td>
</tr>
</tbody>
</table>

Additional parameters under indeterminacy

<table>
<thead>
<tr>
<th></th>
<th>Mean [5th, 95th]</th>
<th>Mean [5th, 95th]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_\xi$</td>
<td>0.212 [0.127, 0.295]</td>
<td></td>
</tr>
<tr>
<td>$M_\alpha$</td>
<td>0.181 [-0.214, 0.576]</td>
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</tr>
<tr>
<td>$M_\beta$</td>
<td>-0.432 [-1.176, 0.326]</td>
<td></td>
</tr>
<tr>
<td>$M_\theta$</td>
<td>0.115 [-0.248, 0.512]</td>
<td></td>
</tr>
<tr>
<td>$M_\sigma$</td>
<td>-0.353 [-0.188, 0.877]</td>
<td></td>
</tr>
<tr>
<td>$M_\pi$</td>
<td>-0.056 [-0.159, 0.046]</td>
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<tr>
<td>$M_\rho$</td>
<td>-0.255 [-0.863, 0.331]</td>
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</tr>
<tr>
<td>$M_\xi$</td>
<td>0.201 [-0.005, 0.409]</td>
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<tr>
<td>$M_\eta$</td>
<td>0.056 [-1.470, 1.560]</td>
<td></td>
</tr>
<tr>
<td>$M_\omega$</td>
<td>0.002 [-0.654, 0.671]</td>
<td></td>
</tr>
</tbody>
</table>

Note: The column labeled [5th, 95th] presents the 5th and 95th percentiles.
Table 5: Variance decompositions of inflation

<table>
<thead>
<tr>
<th>Shocks</th>
<th>Pre-Volcker (PMPF)</th>
<th>Post-Volcker (AMPF)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Short-Run (4 Q)</td>
<td>Long-Run (40 Q)</td>
</tr>
<tr>
<td>Govt. spending</td>
<td>0.006</td>
<td>0.002</td>
</tr>
<tr>
<td>(\varepsilon_{g,t} )</td>
<td>[0.000, 0.024]</td>
<td>[0.000, 0.007]</td>
</tr>
<tr>
<td>Preference</td>
<td>0.194</td>
<td>0.467</td>
</tr>
<tr>
<td>(\varepsilon_{d,t} )</td>
<td>[0.034, 0.402]</td>
<td>[0.119, 0.904]</td>
</tr>
<tr>
<td>Technology</td>
<td>0.359</td>
<td>0.121</td>
</tr>
<tr>
<td>(\varepsilon_{a,t} )</td>
<td>[0.119, 0.601]</td>
<td>[0.006, 0.316]</td>
</tr>
<tr>
<td>Mark-up</td>
<td>0.197</td>
<td>0.210</td>
</tr>
<tr>
<td>(\varepsilon_{u,t} )</td>
<td>[0.073, 0.392]</td>
<td>[0.012, 0.539]</td>
</tr>
<tr>
<td>Transfer</td>
<td>0.010</td>
<td>0.003</td>
</tr>
<tr>
<td>(\varepsilon_{s,t} )</td>
<td>[0.000, 0.038]</td>
<td>[0.000, 0.014]</td>
</tr>
<tr>
<td>Monetary policy</td>
<td>0.107</td>
<td>0.057</td>
</tr>
<tr>
<td>(\varepsilon_{R,t} )</td>
<td>[0.017, 0.271]</td>
<td>[0.002, 0.188]</td>
</tr>
<tr>
<td>Tax revenues</td>
<td>0.027</td>
<td>0.009</td>
</tr>
<tr>
<td>(\varepsilon_{\tau,t} )</td>
<td>[0.001, 0.077]</td>
<td>[0.000, 0.031]</td>
</tr>
<tr>
<td>Inflation target</td>
<td>0.007</td>
<td>0.101</td>
</tr>
<tr>
<td>(\varepsilon_{\pi,t} )</td>
<td>[0.000, 0.029]</td>
<td>[0.001, 0.378]</td>
</tr>
<tr>
<td>Debt target</td>
<td>0.021</td>
<td>0.007</td>
</tr>
<tr>
<td>(\varepsilon_{b,t} )</td>
<td>[0.000, 0.078]</td>
<td>[0.000, 0.029]</td>
</tr>
<tr>
<td>Sunspot</td>
<td>0.072</td>
<td>0.023</td>
</tr>
<tr>
<td>(\varepsilon_{\zeta,t} )</td>
<td>[0.020, 0.161]</td>
<td>[0.001, 0.069]</td>
</tr>
</tbody>
</table>

Note: Means and [5th, 95th] posterior percentiles.
Table 6: Variance decompositions of output growth

<table>
<thead>
<tr>
<th>Shocks</th>
<th>Pre-Volcker (PMPF)</th>
<th>Post-Volcker (AMPF)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Short-Run (4 Q)</td>
<td>Long-Run (40 Q)</td>
</tr>
<tr>
<td>Govt. spending</td>
<td>0.150</td>
<td>0.145</td>
</tr>
<tr>
<td>$\varepsilon_{g,t}$</td>
<td>[0.063, 0.252]</td>
<td>[0.061, 0.245]</td>
</tr>
<tr>
<td>Preference</td>
<td>0.179</td>
<td>0.178</td>
</tr>
<tr>
<td>$\varepsilon_{d,t}$</td>
<td>[0.018, 0.371]</td>
<td>[0.020, 0.369]</td>
</tr>
<tr>
<td>Technology</td>
<td>0.096</td>
<td>0.105</td>
</tr>
<tr>
<td>$\varepsilon_{a,t}$</td>
<td>[0.028, 0.237]</td>
<td>[0.035, 0.240]</td>
</tr>
<tr>
<td>Mark-up</td>
<td>0.340</td>
<td>0.342</td>
</tr>
<tr>
<td>$\varepsilon_{u,t}$</td>
<td>[0.159, 0.546]</td>
<td>[0.162, 0.547]</td>
</tr>
<tr>
<td>Transfer</td>
<td>0.016</td>
<td>0.016</td>
</tr>
<tr>
<td>$\varepsilon_{s,t}$</td>
<td>[0.000, 0.055]</td>
<td>[0.000, 0.054]</td>
</tr>
<tr>
<td>Monetary policy</td>
<td>0.016</td>
<td>0.016</td>
</tr>
<tr>
<td>$\varepsilon_{R,t}$</td>
<td>[0.004, 0.043]</td>
<td>[0.004, 0.043]</td>
</tr>
<tr>
<td>Tax revenues</td>
<td>0.047</td>
<td>0.046</td>
</tr>
<tr>
<td>$\varepsilon_{\tau,t}$</td>
<td>[0.001, 0.140]</td>
<td>[0.001, 0.136]</td>
</tr>
<tr>
<td>Inflation target</td>
<td>0.008</td>
<td>0.007</td>
</tr>
<tr>
<td>$\varepsilon_{\pi,t}$</td>
<td>[0.000, 0.032]</td>
<td>[0.000, 0.031]</td>
</tr>
<tr>
<td>Debt target</td>
<td>0.035</td>
<td>0.034</td>
</tr>
<tr>
<td>$\varepsilon_{b,t}$</td>
<td>[0.000, 0.128]</td>
<td>[0.000, 0.124]</td>
</tr>
<tr>
<td>Sunspot</td>
<td>0.114</td>
<td>0.111</td>
</tr>
<tr>
<td>$\varepsilon_{\zeta,t}$</td>
<td>[0.039, 0.232]</td>
<td>[0.039, 0.227]</td>
</tr>
</tbody>
</table>

Note: Means and [5th, 95th] posterior percentiles.
Appendix

A System of equilibrium conditions

The technology process $A_t$ induces a common trend in output $Y_t$, consumption $C_t$, real wage $\frac{\tilde{W}_t(i)}{P_t}$, government purchases $G_t$, government debt $B_t/P_t$, tax revenues $T_t$, and transfers $S_t$. Since we solve the model through a local approximation of its dynamics around a steady state, we first detrend the variables as

$$\tilde{Y}_t \equiv \frac{Y_t}{A_t}, \quad \tilde{C}_t \equiv \frac{C_t}{A_t}, \quad \text{and} \quad \frac{\tilde{W}_t(i)}{P_t} \equiv \frac{W_t(i)}{P_t A_t}.$$  

Note that the fiscal variables, $b_t = B_t/P_t Y_t$, $g_t = G_t/Y_t$, $\tau_t = T_t/Y_t$, and $s_t = S_t/Y_t$ are already stationary. We then rewrite the equilibrium conditions in terms of the detrended variables, compute the non-stochastic steady state, and then take a first-order approximation around the steady state. In the ensuing subsections, we present the equilibrium conditions in terms of the detrended variables and their first order approximations.

A.1 Equilibrium conditions in terms of detrended variables

- Consumption Euler equation:

$$\beta E_t \left[ \frac{1}{\pi_{t+1}} \left( \tilde{C}_t - \eta \tilde{C}_{t-1} a_t^{-1} \right) \delta_{t+1} \frac{1}{\tilde{a}_{t+1}} \right] = \frac{1}{R_t}.$$  

- Labor supply:

$$(H_t)^{\varphi} \left( \tilde{C}_t - \eta \tilde{C}_{t-1} a_t^{-1} \right) = \frac{\tilde{W}_t(j)}{P_t}.$$  

- Production function:

$$\tilde{Y}_t(i) = H_t(i)$$  

- Demand function:

$$\tilde{Y}_t(i) = [\tilde{p}_t(i)]^{-\theta_t} \tilde{Y}_t, \quad \text{where} \quad \tilde{p}_t(i) = \frac{P_t(i)}{P_t}.$$  

• Firms’ optimality condition:

\[
E_t \sum_{k=0}^{\infty} (\alpha \beta)^k \left( \frac{\tilde{C}_t - \eta \tilde{C}_{t-1} a_t^{-1}}{\tilde{C}_{t+k} - \eta \tilde{C}_{t+k-1} a_{t+k}^{-1}} \right) \delta_{t+k} \tilde{Y}_{t+k}(i) \left[ \frac{\tilde{p}_t(i) X_{t,k}}{\prod_{s=1}^{k} \tilde{p}_{t+s}} - \left( \frac{\theta_t}{\theta_t - 1} \right) \frac{\tilde{W}_{t+k}(j)}{P_{t+k}} \right] = 0.
\]

• Dixit-Stiglitz price aggregator:

\[
1 = \left[ (1 - \alpha) \tilde{p}_t^{\rho p} + \alpha \left\{ \frac{\pi}{\pi_t} \left( \frac{\pi_{t-1}}{\pi_t} \right)^{\rho Y} \right\} \right]^{\frac{1}{1-\rho_c}}.
\]

• Government budget constraint:

\[
b_t = R_{t-1} b_{t-1} \frac{1}{\pi_t} \tilde{Y}_{t-1} \frac{1}{\pi_t} a_t + g_t - \tau_t + s_t.
\]

• Monetary policy rule:

\[
\frac{R_t}{R} = \left( \frac{R_{t-1}}{R} \right)^{\rho r} \left[ \left( \frac{\pi_t}{\pi_t} \right)^{\phi r} \left( \frac{\tilde{Y}_t}{\tilde{Y}_t} \right)^{\phi Y} \right]^{1-\rho_r} e^{\varepsilon_{r,t}}.
\]

• Fiscal policy rule I (Tax rule):

\[
\frac{\tau_t}{\bar{\tau}} = \left( \frac{\tau_{t-1}}{\bar{\tau}} \right)^{\rho r} \left[ \left( \frac{b_{t-1}}{b_{t-1}} \right)^{\phi b} \left( \frac{\tilde{Y}_{t-1}}{\tilde{Y}_{t-1}} \right)^{\phi Y} \right]^{1-\rho_r} e^{\varepsilon_{r,t}}.
\]

• Fiscal policy rule II (Government spending rule):

\[
\frac{g_t}{\bar{g}} = \left( \frac{g_{t-1}}{\bar{g}} \right)^{\rho g} \left( \frac{\tilde{Y}_{t-1}}{\tilde{Y}_{t-1}} \right)^{-\phi Y (1-\rho_g)} e^{\varepsilon_{g,t}}.
\]

• Resource constraint:

\[
\tilde{Y}_t = \tilde{C}_t + g_t \tilde{Y}_t.
\]

A.2 First order approximation

We here present first-order approximation of the equations that are necessary to determine equilibrium dynamics of the observables.
Consumption Euler equation:
\[
\hat{C}_t = \frac{a}{a + \eta} E_t \hat{C}_{t+1} + \frac{\eta}{a + \eta} \hat{C}_{t-1} - \frac{a - \eta}{a + \eta} \left( \hat{R}_t - E_t \hat{\pi}_{t+1} \right) + \frac{a}{a + \eta} E_t \hat{\alpha}_{t+1} - \frac{\eta}{a + \eta} \hat{\alpha}_t + \frac{a - \eta}{a + \eta} \hat{\delta}_t,
\]
where \( \hat{\delta}_t \equiv (1 - \rho_b) \hat{\delta}_t \).

NK Phillips curve:
\[
\hat{\pi}_t = \frac{\beta}{1 + \gamma \beta} E_t \hat{\pi}_{t+1} + \frac{\gamma}{1 + \gamma \beta} \hat{\pi}_{t-1} + \kappa \left[ \left( \varphi + \frac{a}{a - \eta} \right) \hat{Y}_t - \frac{\eta}{a - \eta} \hat{Y}_{t-1} + \left( \frac{\eta}{a - \eta} \right) \hat{\alpha}_t \right] + \hat{u}_t,
\]
where \( \kappa \equiv \frac{(1 - \alpha)(1 - \alpha)}{a(1 - \varphi^2)(1 + \gamma \beta)} \) and \( \hat{u}_t \equiv -\kappa \frac{1}{\sigma - 1} \hat{\theta}_t \) can be interpreted as cost-push shocks.

Monetary policy rule:
\[
\hat{R}_t = \rho_R \hat{R}_{t-1} + (1 - \rho_R) \left[ \phi_R (\hat{\pi}_t - \hat{\pi}_t^*) + \phi_Y \left( \hat{Y}_t - \hat{Y}_t^* \right) \right] + \hat{\varepsilon}_{R,t}.
\]

Fiscal policy rule I:
\[
\hat{b}_t = \rho_r \hat{b}_{t-1} + (1 - \rho_r) \left[ \psi_b \left( \hat{b}_{t-1} - \hat{b}_{t-1}^* \right) + \psi_Y \left( \hat{Y}_{t-1} - \hat{Y}_{t-1}^* \right) + \psi_g \hat{g}_t \right] + \hat{\varepsilon}_{\tau,t},
\]
where \( \psi_b, \psi_Y \) and \( \psi_g \) are respectively scaled counterparts of \( \hat{\psi}_b, \hat{\psi}_Y \) and \( \hat{\psi}_g \):
\[
\psi_b \equiv \frac{\tilde{\tau}}{b} \hat{\psi}_b, \quad \psi_Y \equiv \frac{\tilde{\tau}}{Y} \hat{\psi}_Y, \quad \psi_g \equiv \frac{\tilde{\tau}}{g} \hat{\psi}_g,
\]
and \( \hat{\varepsilon}_{\tau,t} \) is given as:
\[
\hat{\varepsilon}_{\tau,t} \equiv \tilde{\tau} \hat{\varepsilon}_{\tau,t} \sim i.i.d. \, N \left( 0, \sigma^2_{\tau,t} \right).
\]

Fiscal policy rule II:
\[
\hat{g}_t = \rho_g \hat{g}_{t-1} - (1 - \rho_g) \chi_Y \left( \hat{Y}_{t-1} - \hat{Y}_{t-1}^* \right) + \hat{\varepsilon}_{g,t},
\]
where \( \chi_Y \equiv \tilde{g}_Y \), and \( \hat{\varepsilon}_{g,t} \equiv \tilde{g}_Y \hat{\varepsilon}_{g,t} \sim i.i.d. \, N \left( 0, \sigma^2_{g,t} \right).

Government budget constraint:
\[
\hat{b}_t = \beta^{-1} \hat{b}_{t-1} + \beta^{-1} b \left( \hat{R}_{t-1} - \hat{\pi}_t - \hat{Y}_t + \hat{Y}_{t-1} - \hat{\alpha}_t \right) + \hat{g}_t - \hat{\tau}_t + \hat{\delta}_t
\]
• Resource constraint:

\[ \hat{Y}_t = \hat{C}_t + \frac{1}{1-g\hat{g}_t} \]

• Natural level of output:

\[ \hat{Y}^*_t = \frac{\eta}{\varphi(a-\eta) + a} \hat{Y}^*_{t-1} + \frac{a}{[\varphi(a-\eta) + a](1-g)}\hat{g}_t^* - \frac{\eta}{\varphi(a-\eta) + a} \hat{g}^*_{t-1} \]

where \( \hat{g}^*_t \) is government spending-to-output ratio that would prevail under flexible prices.

• AR(1) processes for exogenous shocks:

\[ \hat{d}_t = \rho_d \hat{d}_{t-1} + \varepsilon_{d,t}, \]
\[ \hat{a}_t = \rho_a \hat{a}_{t-1} + \varepsilon_{a,t}, \]
\[ \hat{u}_t = \rho_u \hat{u}_{t-1} + \varepsilon_{u,t}, \]
\[ \hat{s}_t = \rho_s \hat{s}_{t-1} + \varepsilon_{s,t}, \]
\[ \hat{\pi}_t^* = \rho_{\pi} \hat{\pi}_{t-1}^* + \varepsilon_{\pi,t}, \]
\[ \hat{b}_t^* = \rho_b \hat{b}_{t-1}^* + \varepsilon_{b,t}. \]
B Data description

We use the following definitions for our data variables: per capita output = (personal consumption of nondurable+personal consumption of services+government consumption) / civilian noninstitutional population; annualized inflation = \(400 \times \Delta \log(\text{GDP deflator})\); annualized interest rates = the quarterly average of daily effective federal funds rates; tax revenues = current tax receipts + contributions for government social insurance; government debt = market value of privately held gross federal debt; and government purchases = government consumption. Note that we use a single price level, GDP deflator, for all the model variables (e.g. output, government debt, tax revenues, and government purchases).

The effective federal funds rate and civilian noninstitutional population data were obtained from the FRED database of Federal Reserve Bank of St. Louis. The market value of privately held gross federal debt series was obtained from Federal Reserve Bank of Dallas. All the other data were taken from National Income and Product Accounts (NIPA) tables.

C Solution method under indeterminacy

This section describes the solution method of a linear rational expectations (LRE) model under indeterminacy proposed by Lubik and Schorfheide (2004). Then we discuss an identification problem in their method and how to address the problem.

C.1 Sims (2002)

Lubik and Schorfheide (2004) starts with the following canonical form of LRE models by Sims (2002)

\[ \Gamma_0 z_t = \Gamma_1 z_{t-1} + \Psi \epsilon_t + \Pi \eta_t, \]

where \( z_t \) is an \( n \times 1 \) vector of model variables, \( \epsilon_t \) is an \( l \times 1 \) vector of fundamental shocks, and \( \eta_t \) is a \( k \times 1 \) vector of expectational errors, satisfying \( E_t \eta_{t+1} = 0 \). We consider a case in which the exogenous fundamental shock process \( \epsilon_t \) is serially uncorrelated. Using the QZ (generalized Schur) decomposition, the coefficient matrices \( \Gamma_0 \) and \( \Gamma_1 \) can be decomposed as \( \Gamma_0 = Q' \Lambda Z' \), \( \Gamma_1 = Q' \Omega Z' \) where \( \Lambda \) and \( \Omega \) are upper triangular and \( Q \) and \( Z \) are unitary: \( QQ' = Q'O = I \) and \( ZZ' = Z'Z = I \). Let \( w_t = Z'z_t \) and multiply both sides of Equation (5)

\[^{44}\text{A model with a serially correlated shock process can always be rewritten so that the model has a serially uncorrelated shock process by augmenting} y_t \text{ to include the original shock process.}\]
by $Q$ to obtain

$$
\begin{bmatrix}
\Lambda_{11} & \Lambda_{12} \\
0 & \Lambda_{22}
\end{bmatrix}
\begin{bmatrix}
w_{1,t} \\
w_{2,t}
\end{bmatrix} =
\begin{bmatrix}
\Omega_{11} & \Omega_{12} \\
0 & \Omega_{22}
\end{bmatrix}
\begin{bmatrix}
w_{1,t-1} \\
w_{2,t-1}
\end{bmatrix} +
\begin{bmatrix}
Q_1 \\
Q_2
\end{bmatrix} (\Psi \varepsilon_t + \Pi \eta_t),
$$

where the generalized eigenvalues of the QZ decomposition (the ratios of diagonal elements of $\Omega$ and $\Lambda$) are ordered such that explosive eigenvalues (ones that do not meet the growth condition for $z_t$) are in the lower right corner and $\Lambda$, $\Omega$ and $Q$ are partitioned accordingly.

Now suppose that there are $m$ unstable generalized eigenvalues ($m \leq n$). That is, $Q_2$ is an $m \times n$ matrix. When the explosive components (decoupled from the first stable components) are solved forward, it is a function of the current and future values of $\varepsilon_t$ and $\eta_t$. For a stable solution to Equation (5) to exist, this forward solution of the unstable part should be constant and therefore it should hold that

$$
Q_2 (\Psi \varepsilon_t + \Pi \eta_t) = 0.
$$

(6)

Since $\varepsilon_t$ is exogenous, we need $\eta_t$ to be determined so that the condition (6) is satisfied (for every possible path of $\varepsilon_t$). The condition (6) is satisfied when the column space spanned by $Q_2 \Psi$ be contained by the column space spanned by $Q_2 \Pi$.

### C.2 Lubik and Schorfheide (2004)

A necessary and sufficient condition that a solution to (5) be unique is that the row space spanned by $Q_1 \Pi$ be contained by the row space spanned by $Q_2 \Pi$. Then, the expectational error for the stable part is expressed as a function of the fundamental shock. The condition is met when there exists a conformable matrix $\Phi$ such that

$$
Q_1 \Pi = \Phi Q_2 \Pi.
$$

(7)

When the condition (6) is satisfied but (7) is not, $\eta_t$ is not completely pinned down by $\varepsilon_t$.

There always exists a singular value decomposition (SVD) of $Q_2 \Pi$ as

$$
Q_2 \Pi =
\begin{bmatrix}
U_1 & U_2
\end{bmatrix}
\begin{bmatrix}
D_{11} & 0 \\
0 & 0
\end{bmatrix}
\begin{bmatrix}
V_1^r \\
V_2^{(k-r)}
\end{bmatrix},
$$

(8)

where $D_{11}$ is a diagonal matrix with nonzero singular values on its diagonal and $U = \begin{bmatrix} U_1 & U_2 \end{bmatrix}$.
and $V = \begin{bmatrix} V_1 & V_2 \end{bmatrix}$ are unitary. Suppose that there are $r \leq m$ nonzero singular values. Then the $m$ explosive components of $z_t$ generate only $r$ restrictions for $\eta_t$. When $r = m$, we have enough restrictions to pin down the expectations of the model and there exists a unique solution. Otherwise, there exist multiple equilibria.

Lubik and Schorfheide (2004) introduce sunspot shocks and assume that the undetermined dimensions of $\eta_t$ are affected by the sunspot shocks additively. Let

$$\eta_t = A_1 \varepsilon_t + A_2 \zeta_t^*,$$

where $\zeta_t^*$ is a $p \times 1$ vector of sunspot shocks with $E_t \zeta_t^* = 0$, $A_1$ is a $k \times l$ matrix and $A_2$ is a $k \times p$ matrix. Then $A_1$ and $A_2$ characterize the full set of solutions to the model (5). Lubik and Schorfheide (2004) show that the full set of solutions are given as

$$\eta_t = (-V_1 D_{11}^{-1} U_1' Q_2 \Psi + V_2 M_1) \varepsilon_t + V_2 M_2 \zeta_t^*, \quad (9)$$

where $M_1$ is a $(k - r) \times l$ matrix and $M_2$ is a $(k - r) \times p$ matrix. When there exists a unique solution or $r = k$, $V_2 = 0$ and and the unique solution is not affected by the sunspot shock $\zeta_t^*$. When there exist multiple solutions or $r < k$, $\zeta_t^*$ affects $z_t$ through their influence on $\eta_t$ and also the impact of $\varepsilon_t$ on $\eta_t$ changes. The new parameters $M_1$ and $M_2$ are not determined by the structural parameters and Lubik and Schorfheide (2004) propose to treat them as additional parameters. Since $M_2$ is not identified in the model, only $(k - r)$ dimensions of the sunspot shocks matter. Lubik and Schorfheide (2004) reparameterize $\zeta_t = M_2 \zeta_t^*$. Putting the solution of the expectational error $\eta_t$, (9), back to the model (5), a solution of the model can be written as

$$z_t = \Gamma_1^* z_{t-1} + (\Gamma_{0,\varepsilon}^* + \Gamma_{0,\zeta}^* M) \varepsilon_t + \Gamma_{0,\zeta}^* \zeta_t. \quad (10)$$

### C.3 Identification problem

An identification problem arises because $V_2$, the left singular vectors of a SVD of $Q_2 \Pi$ in (8), corresponds to zero singular values and thus is not identified. Because of this problem, $\Gamma_{0,\zeta}^*$ in (10) is not well identified. This appears to cause numerical instability in their solution method. For example, small changes in parameter values can easily lead to a large change in the likelihood of a LRE model under indeterminacy.

Since in our model the degree of indeterminacy is at most one, $\Gamma_{0,\zeta}^*$ is simply a vector. We identify $\Gamma_{0,\zeta}^*$ by normalizing its first entry to its norm. With this normalization, posterior density maximization and simulation of our model is stable and works well. The normalization would affect the posterior distribution of the entries of the matrix $M$ in (10). However, those
parameters in $M$ do not have behavioral interpretations. What matters is the additional channel for the propagation of the fundamental shocks, $\Gamma_0^\ast M$, whose posterior distribution is not affected by the normalization if the prior distribution for the entries of $M$ is flat. Although our baseline prior for the entries of $M$ is not completely flat, it is very diffuse and the effect of the normalization is not significant. We tried different specifications for the prior distribution for the entries of $M$, including a uniform prior distribution over $(-5, 5)$ and our results were robust to these variations. The same argument applies to $\zeta_i$.

D Estimation methods and convergence diagnostics

Since it is difficult to characterize analytically the posterior distribution of the structural parameters, we use a Markov chain Monte Carlo (MCMC) simulation. We first find a mode of the posterior density numerically using csminwel by Christopher A. Sims. Then a random-walk Metropolis algorithm is used to draw a sample from the posterior distribution. The proposal density of the random-walk Metropolis algorithm is a Normal distribution whose mean is the previous successful draw and variance is the inverse of the negative Hessian at the posterior mode found before the simulation. The variance of the proposal density is scaled to achieve an acceptance rate of around 30%. We run three separate MCMC chains with over-dispersed starting values for each policy regime of each subsample. For each chain, we make 2.4 million draws but burn in the first 0.4 million draws. To save the disk space, we thin the MCMC chains by keeping every 8th draw.

To assess convergence of our posterior simulation, two diagnostics are used. First, we estimate the potential scale reduction factor (PSRF) that compares the within-chain and between-chain variance of MCMC chains. A PSRF would be close to 1 when MCMC chains converge. For most of the parameters, PSRF estimates and the upper bound of their 95% confidence intervals are effectively 1. Though some parameters have PSRF estimates greater than 1, the estimates are still less than 1.1, which is the rule-of-thumb value commonly used in the literature as an upper limit for good convergence. Second, we inspect convergence visually by plotting the recursive means of MCMC output. The recursive mean plots suggest good mixing of MCMC chains.\footnote{A detailed report on convergence diagnostics with the PSRF estimates and recursive mean plots are available on request from the authors.}
E The role of fiscal policy

Figure 10: Impulse responses to monetary policy shocks in the pre-Volcker period

Note: Figure plots pointwise posterior means (solid lines) and 90-percent probability intervals (dashed lines) for impulse responses to a one standard deviation shock to $\varepsilon_{R,t}$. The results are for the PM regime pre-Volcker, with three different sets of priors on the matrix $M$. There is no fiscal policy in the model and fiscal variables are dropped in the estimation. Prior 1 denotes the prior used in Lubik and Schorfheide (2004), prior 2 denotes our baseline prior (that is, $N(0,1)$), and prior 3 denotes the diffuse prior (that is, $Uniform(-5,5)$). The unit of the impulse responses is percentage deviations from the steady state for output and percentage point deviations from the steady state for the rest of the variables.
Figure 11: Impulse responses to monetary policy shocks in the pre-Volcker period

Note: Figure plots pointwise posterior means (solid lines) and 90-percent probability intervals (dashed lines) for impulse responses to a one standard deviation shock to $\varepsilon_{R,t}$. The results are for the PMPF regime pre-Volcker, with three different sets of priors on the matrix $M$. Prior 1 denotes the prior used in Lubik and Schorfheide (2004), prior 2 denotes our baseline prior (that is, $N(0,1)$), and prior 3 denotes the diffuse prior (that is, $Uniform(-5,5)$). The unit of the impulse responses is percentage deviations from the steady state for output and percentage point deviations from the steady state for the rest of the variables.