Do We Really Know that U.S. Monetary Policy was Destabilizing in the 1970s?

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Abstract

The paper re-examines whether the Federal Reserve's monetary policy was a source of instability during the Great Inflation by estimating a sticky-price model with positive trend inflation, commodity price shocks and sluggish real wages. Our estimation provides empirical evidence for substantial wage rigidity and finds that the Federal Reserve responded aggressively to inflation but negligibly to the output gap. In the presence of non-trivial real imperfections and well-identified commodity price-shocks, U.S. data prefers a determinate version of the New Keynesian model: monetary policy-induced indeterminacy and sunspots were not causes of macroeconomic instability during the pre-Volcker era. However, had the Federal Reserve in the Seventies followed the policy rule of the Volcker-Greenspan-Bernanke period, inflation volatility would have been lower by one third.

Keywords: Monetary policy, Trend inflation, Great Inflation, Cost-push shocks, Indeterminacy.

JEL codes **E32**, **E52**, **E58**.

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1 Introduction

The Great Inflation was one of the defining macroeconomic chapters of the twentieth century. From the late 1960s and throughout the 1970s, the U.S. economy experienced both turbulent business cycle fluctuations as well as unprecedented high and volatile rates of inflation. By 1979 inflation hovered above 15 percent. Since the seminal works by Clarida et al. (2000) and Lubik and Schorfheide (2004), a dominant narrative of this historical episode attributes the exacerbated macroeconomic fluctuations and elevated inflation to poorly designed monetary policy: the Federal Reserve's weak response to inflation generated equilibrium multiplicity and the resulting instability and sunspot shocks nourished further inflation movements. On the other hand, Gordon (1977) and Blinder (1982), among others, have singled out cost-push shocks – mainly arising from spikes in the prices of food and oil – as the principal causes of the 1970s' stagflation.[1] Such cost-push shocks are largely absent from the more recent studies of the Great Inflation that focus on the interplay of monetary policy and indeterminacy.

This paper re-examines these two views by estimating a sticky-price model to which we add three key factors that are often put forward as distinctive features of the Great Inflation period: positive trend inflation (Coibion and Gorodnichenko, 2011, and Ascari and Sbordone, 2014), commodity price shocks and real wage rigidity (Blanchard and Galí, 2010, and Blanchard and Riggi, 2013). In this version of a Generalized New Keynesian (GNK) economy, commodity price disturbances and wage rigidity generate a strong negative correlation between inflation and the output gap, thereby confronting the monetary authority with a difficult trade-off.[2] This trade-off is important as it explains why our estimates of the Taylor rule parameters – in particular, a very weak response to the output gap and strong response to inflation and output growth – are different from the ones obtained by other studies of the Great Inflation. As in Hirose et al. (2017), we employ Bayesian techniques featuring the Sequential Monte Carlo (SMC) sampling algorithm proposed by Herbst

[1] See also Blinder and Rudd (2012) for a recent resurrection of this line of thought and Barsky and Kilian (2001) for a critical evaluation.

[2] Following Ascari and Sbordone (2014), we use the term GNK to refer to the New Keynesian model loglinearized around a positive steady-state inflation rate.

and Schorfheide (2014) to uncover the posterior distribution of the model's parameters over the entire parameter space.[3] This upgrade is particularly relevant given the discontinuity that arises in the posterior distribution along the boundary between the determinacy and indeterminacy regions of the model. We estimate the artificial economy using quarterly observations on six key macroeconomic variables that are essential to properly identifying cost-push shocks and their propagation as well as wage dynamics.

Our central claim is that we can rule out indeterminacy as a source of instability during the Great Inflation period. The underlying mechanism to this result is connected to monetary policy, in particular to the central bank's response to inflation and the output gap, as well as to the degree of wage sluggishness. Positive trend inflation changes the parametric region of indeterminacy. As a result, adhering to the Taylor Principle is no longer sufficient to rule out indeterminacy. In particular, a strong systematic response of the policy rate to the output gap increases the chance of multiple equilibria, while reacting forcefully to output growth stabilizes the economy (Ascari and Ropele 2009; Coibion and Gorodnichenko 2011). In fact, these upshots conjoin to our estimated Taylor-type rule for the pre-Volcker period: it is active with respect to inflation as in Hirose et al. (2019) but, at the same time, it entails a weaker response to the output gap and a stronger one to output growth. Our interpretation is that the central bank's response reflects the aforementioned trade-off between inflation and output gap stabilization in the presence of oil price shocks. An important element for this trade-off is a certain degree of real wage rigidity, a factor that has also been found to be important for understanding other macroeconomic puzzles.[4] Along these lines, we make two contributions. First, we provide new theoretical insights regarding how wage sluggishness dampens the effect of trend inflation on equilibrium instability. Second, in the context of our estimated model, we find evidence for high degree of rigidity in wage dynamics. Then the estimated Taylor Rule involves a more

[3]See also Ascari et al. (2019) for a different approach to estimation using SMC that relies on particle learning.

[4]See, for example, Barsky et al. (2015), Blanchard and Galí (2010), Blanchard and Riggi (2013), Hall (2005), Jeanne (1990), Michaillat (2012) and Uhlig (2007). Beaudry and DiNardo (1991) and others find micro-evidence along these lines. However, Basu and House (2016) suggest that a considerable portion of this rigidity disappears when accounting for heterogeneity.

active response to inflation, a stronger response to output growth and a close to non-existent response to the output gap. This combination is key for our determinacy result during the pre-Volcker era.

When we estimate our model over the Great Moderation period, the interest rate responses to inflation and output growth almost double, while trend inflation falls considerably. These patterns are consistent with the findings of Coibion and Gorodnichenko (2011) and Hirose et al. (2017). Also, the Federal Reserve moves its focus away from responding to headline inflation toward core inflation (Mehra and Sawhney, 2010), implying a less contractionary response of monetary policy to oil price shocks. Finally, wages become more flexible during the Great Moderation period and therefore oil price shocks are no longer as stagflationary as in the 1970s, which is in line with Blanchard and Gali's (2010) hypothesis as to why the 2000s are so different from the 1970s. Do our results then imply that monetary policy had no destabilizing effect during the Seventies? No. In fact, using a counterfactual experiment, we show that had the Federal Reserve followed the policy rule of the Volcker-Greenspan-Bernanke era already during the Seventies, inflation volatility would have been reduced by one third.

Our paper stands in line with Lubik and Schorfheide (2004) who, building on Clarida at al. (2000), were the first to estimate a standard New Keynesian model to find that the Federal Reserve's passive response to inflation resulted in sunspot equilibria in the 1970s.[5] Hirose et al. (2019) take into consideration the role of positive trend inflation and upgrade the Bayesian estimation techniques by replacing the Markov chain Monte Carlo algorithm with the SMC algorithm. Like Coibion and Gorodnichenko (2011), they find that the Federal Reserve's policy before Volcker induced sunspot equilibria. These investigations of the link between monetary policy and equilibrium stability have sidestepped the explicit treatment of commodity price fluctuations and the policy trade-off that these disturbances can generate. Only Nicolò (2019) estimates a medium-scale model with cost push shocks similar to Smets and Wouters (2007). However, he elides trend inflation.[6] Also, we model commodity

[5] Ascari et al. (2019) take an alternative path that involves temporarily explosive paths to explain the Great Inflation episode.

[6] Arias et al. (2019) also work off a medium-scale model with trend inflation but avoid estimating

price shocks in a more explicit way which allows us to use particular observables that sharpen the shocks' identification. In fact, this aspect of our econometric strategy matters in a crucial way for the behavior of the output gap and thereby for the posterior estimates of the Taylor-rule coefficients. As we show, our estimates of the latent model-consistent output-gap exhibit fluctuations that closely resemble the ones displayed by conventional measures such at the CBO's output gap. There are several studies of oil's role from a general equilibrium perspective. Natal (2012), for example, considers an alternative mechanism to real wage rigidity through which supply shocks can create a policy trade-off. His approach relies on the interaction between monopolistic competition and the substitutability of oil. Nakov and Pescatori (2010) and Bjørnland et al. (2018) study the role of oil in driving the Great Moderation. Lastly, Blanchard and Riggi (2013) and Bodenstein et al. (2008) examine the role of wage stickiness in the presence of oil price disturbances. More concretely, the former examines structural changes in the economy that have modified the transmission mechanism of oil shocks and the latter addresses optimal monetary policy design in the presence of commodity price shocks. Thus, none of these papers have examined whether or not monetary policy was a source of indeterminate equilibria and, therefore, instability during the Great Inflation.

2 Model

The artificial economy is a GNK model with a commodity product that we interpret as mainly oil. The economy consists of monopolistically competitive wholesale firms that produce differentiated goods using labor and oil. These goods are bought by perfectly competitive firms that weld them together into the final good that can be consumed. People rent out their labor services and labor markets are characterized by wage rigidity. Firms and households are price takers on the market for oil.[7]

the indeterminate version of the model since it involves higher order indeterminacy.

[7] The economy boils down to a variant of Blanchard and Galí (2010) when approximated around a zero inflation steady state. The Appendix provides details of the model.

2.1 People

The economy is populated by a representative agent whose preferences over consumption C_t and hours worked N_t are ordered by

$$E_0 \sum_{t=0}^{\infty} \beta^t d_t \left[\ln \left(C_t - h\widetilde{C}_{t-1} \right) - \nu_t \frac{N_t^{1+\varphi}}{1+\varphi} \right]$$

where E_t is the expectations operator conditioned on time t information, β represents the discount factor, $h\widetilde{C}_{t-1}$ is external habit in consumption taken as exogenous by the agent where $0 \leq h < 1$, and φ is the inverse of the Frisch labor supply elasticity. Disturbances to the discount factor are denoted by preference shocks d_t while ν_t stands for shocks to the disutility of labor. Both disturbances follow AR(1) processes:

$$\ln d_t = \rho_d \ln d_{t-1} + \epsilon_{d,t}$$

and

$$\ln \nu_t = \rho_\nu \ln \nu_{t-1} + \epsilon_{\nu,t}.$$

Here $\epsilon_{d,t}$ and $\epsilon_{\nu,t}$ are independently and identically distributed, $N(0, \sigma_d^2)$ and $N(0, \sigma_v^2)$ respectively. Consumption is a Cobb-Douglas basket of domestically produced goods $C_{q,t}$ and imported oil $C_{m,t}$

$$C_t = \Theta_\chi C_{m,t}^{\chi} C_{q,t}^{1-\chi} \qquad 0 \leq \chi < 1, \; \Theta_\chi \equiv \chi^{-\chi}(1-\chi)^{-(1-\chi)}$$

where χ is the elasticity of oil in consumption. We denote the core consumer price index by $P_{q,t}$, the price of oil by $P_{m,t}$ and the headline consumer price index is then given by

$$P_{c,t} \equiv P_{m,t}^{\chi} P_{q,t}^{1-\chi}. \tag{1}$$

People sell labor services to wholesale firms at the nominal wage W_t. They have access to a market for one-period riskless discount bonds B_t at the interest rate R_t. All profits Π_t flow back to households and the budget constraint in period t is given by

$$W_t N_t + B_{t-1} + \Pi_t \geq P_{q,t} C_{q,t} + P_{m,t} C_{m,t} + \frac{B_t}{R_t}.$$

Then, the agent's first-order conditions imply

$$\frac{d_t}{P_{c,t}\left(C_t - hC_{t-1}\right)} = \beta E_t \frac{R_t d_{t+1}}{P_{c,t+1}\left(C_{t+1} - hC_t\right)}$$

and

$$\frac{W_t}{P_{c,t}} = \nu_t N_t^{\varphi} \left(C_t - hC_{t-1}\right). \tag{2}$$

2.2 Firms

Two kinds of firms exist. Perfectly competitive final good firms produce the homogenous good Q_t by choosing a combination of intermediate inputs $Q_t(i)$ subject to a Constant Elasticity of Substitution production technology. With $P_{q,t}(i)$ as the price of the intermediate good i and ε as the elasticity of substitution between any two differentiated goods, the demand for good i is given by

$$Q_t(i) = \left(\frac{P_{q,t}(i)}{P_{q,t}}\right)^{-\varepsilon} Q_t. \tag{3}$$

There is a continuum of intermediate goods producers using labor N_t and (imported) oil M_t. Each firm i produces according to the production function

$$Q_t(i) = M_t(i)^{\alpha} \left[A_t N_t(i)\right]^{1-\alpha} \qquad 0 \leq \alpha < 1$$

in which α is the share of oil in production and A_t denotes non-stationary labor-augmenting technology that follows

$$\ln A_t = \ln \overline{g} + \ln A_{t-1} + \epsilon_{g,t}.$$

Here, $\overline{g}$ stands for the steady-state gross rate of technological change and $\epsilon_{g,t}$ is independently and identically distributed $N(0, \sigma_g^2)$. Cost minimization implies that the firm's demand for oil is

$$M_t(i) = \frac{\alpha}{\mathcal{M}_t^P(i)} \frac{Q_t(i)}{s_t} \frac{P_{q,t}(i)}{P_{q,t}} \tag{4}$$

where $\mathcal{M}_t^P(i)$ is the firm's gross markup of price over marginal cost and $s_t \equiv \frac{P_{m,t}}{P_{q,t}}$ is the real price of oil which follows

$$\ln s_t = \rho_s \ln s_{t-1} + \epsilon_{s,t}$$

with $\epsilon_{s,t}$ independently and identically distributed $N(0, \sigma_s^2)$. Aggregating over all i and defining $\Delta_t \equiv \int_0^1 (\frac{P_{q,t}(i)}{P_{q,t}})^{-\varepsilon} di$ as the measure of relative price dispersion, (4) becomes

$$M_t = \frac{\alpha}{\mathcal{M}_t^P} \frac{Q_t}{s_t} \Delta_t^{\frac{\varepsilon-1}{\varepsilon}}$$

where the average gross markup is $\mathcal{M}_t^P \equiv \int_0^1 \mathcal{M}_t^P(i)di$. Next, combining the cost minimization condition and the production function yields the factor price frontier:

$$\left(\frac{W_t}{P_{c,t}}\right)^{1-\alpha} \mathcal{M}_t^P = \mathcal{C} A_t^{1-\alpha} s_t^{-\alpha-\chi(1-\alpha)} \Delta_t^{-\frac{1}{\varepsilon}}$$

where $\mathcal{C}$ is a constant that depends on α and χ. The intermediate goods producers face a constant probability $0 < 1 - \xi < 1$ of being able to adjust prices to $P_{q,t}^*(i)$ to maximize expected discounted profits

$$E_t \sum_{j=0}^{\infty} \xi^j \frac{\Lambda_{t,t+j}}{P_{q,t+j}} \left[P_{q,t}^*(i) Q_{t+j}(i) - \frac{\alpha^{-\alpha}}{(1-\alpha)^{1-\alpha}} \left(\frac{W_{t+j}}{A_{t+j}}\right)^{1-\alpha} (P_{m,t+j})^{\alpha} Q_{t+j}(i) \right]$$

subject to the demand schedule (3) where $\Lambda_{t,t+j}$ is the stochastic discount factor. The first-order condition for the relative price $p_{q,t}^*(i) \equiv \frac{P_{q,t}^*(i)}{P_{q,t}}$ is

$$p_{q,t}^*(i) = \frac{\varepsilon}{(\varepsilon-1)(1-\alpha)} \frac{E_t \sum_{j=0}^{\infty} \xi^j \Lambda_{t,t+j} \frac{W_{t+j}}{P_{q,t+j} A_{t+j}^{1-\alpha}} \left[\frac{(1-\alpha) P_{m,t+j}}{\alpha W_{t+j}}\right]^{\alpha} \left[\frac{P_{q,t}}{P_{q,t+j}}\right]^{-\varepsilon} Q_{t+j}}{E_t \sum_{j=0}^{\infty} \xi^j \Lambda_{t,t+j} \left[\frac{P_{q,t}}{P_{q,t+j}}\right]^{1-\varepsilon} Q_{t+j}}.$$

Finally, the condition that trade is balanced yields a relation between aggregate consumption C_t, gross output Q_t and gross domestic product Y_t:

$$P_{c,t} C_t = P_{q,t} Q_t - P_{m,t} M_t = \left(1 - \frac{\alpha}{\mathcal{M}_t^P} \Delta_t^{\frac{\varepsilon-1}{\varepsilon}}\right) P_{q,t} Q_t = P_{y,t} Y_t$$

where $P_{y,t}$ is the GDP deflator implicitly defined by

$$P_{q,t} \equiv (P_{y,t})^{1-\alpha} (P_{m,t})^{\alpha}.$$

2.3 Monetary policy

The central bank adjusts the short-term nominal interest rate R_t according to the Taylor-type rule

$$\frac{R_t}{\overline{R}} = \left(\frac{R_{t-1}}{\overline{R}}\right)^{\rho_R} \left(\left[\left(\frac{\pi_{c,t}}{\overline{\pi}}\right)^{\tau} \left(\frac{\pi_{q,t}}{\overline{\pi}}\right)^{1-\tau} \right]^{\psi_\pi} \left[\frac{Y_t}{Y_t^*}\right]^{\psi_x} \left[\frac{Y_t/Y_{t-1}}{\overline{g}}\right]^{\psi_g} \right)^{1-\rho_R} e^{\epsilon_{R,t}}. \quad (5)$$

Here $\overline{R}$ is the steady state gross nominal interest rate and $\overline{\pi}$ denotes the central bank's inflation target (which is also the steady state level of inflation, i.e. trend inflation). Mehra and Sawhney (2010) suggest that the Federal Reserve used different inflation measures to inform policy decisions. In the model, this translates into the central bank responding to a convex combination of headline and core inflation rates governed by the weight $0 \leq \tau \leq 1$. The coefficients ψ_π, ψ_x and ψ_g dictate the central bank's response to the inflation gap, output gap and output growth respectively. Following Blanchard and Galí (2007) and Blanchard and Riggi (2013), the output gap here measures the deviation of actual GDP from its efficient level Y_t^*, defined as the allocation under flexible prices and perfect competition in goods and labor markets.[8] The policy rule further allows for interest rate smoothing via $0 \leq \rho_R < 1$. Policy shocks $\epsilon_{R,t}$ are independently and identically distributed $N(0, \sigma_R^2)$.

2.4 Real wage sluggishness

Departing from the above, we allow for real wage rigidities. Such rigidities have been found to be important in understanding the macroeconomic effect of oil price shocks (Blanchard and Galí, 2010, and Blanchard and Riggi, 2013), news shocks (Barsky et al., 2015), the behavior of labor markets (Hall, 2005, Michaillat, 2012) and asset markets (Uhlig, 2007) and the propagation of monetary policy shocks (Jeanne, 1990). We follow these insights and let wages adjust only partially, representing frictions not explicitly considered here. As pointed out by Blanchard and Galí (2007), this parsimonious formulation of wage rigidity entails micro-founded makeups without the need to confine to a particular one. Wage sluggishness modifies the intratemporal optimality condition (2) to

$$\frac{W_t}{P_{c,t}} = \left(\frac{W_{t-1}}{P_{c,t-1}}\right)^\gamma \left(\nu_t N_t^\varphi \left(C_t - hC_{t-1}\right)\right)^{1-\gamma} \qquad 0 \leq \gamma < 1$$

where γ determines the degree of rigidity, which will be a key parameter in the estimation. This modification looks after the possibility that model estimations with a flexible wage specification ascribe wage dynamics to shocks when instead those dynamics are more accurately modelled as frictions. We will use an agnostic prior for γ to let the data speak. If the data prefers the original micro-founded specification, the estimation procedure remains free to select a value of γ close to zero.

[8] Blanchard and Riggi (2013) show that in a model with real wage rigidities, the flexible-price output gap may fluctuate a lot in response to oil price shocks. In contrast, the welfare-relevant output gap is less volatile and appears closer to what the Federal Reserves actually looks at.

2.5 Equilibrium dynamics

New Keynesian models are prone to indeterminacy and this is particularly the case in versions with trend inflation. Real wage rigidity affects the dynamic properties of the economy as well. To show this, Figure 1 plots the indeterminacy regions of the linearized model in the $\psi_\pi - \gamma$ space for various levels of trend inflation.[9] In the absence of any real wage rigidity, i.e. $\gamma = 0$, the minimum responsiveness to inflation required to generate determinacy rises with trend inflation. Ascari and Ropele (2009) show that trend inflation makes price-setting firms more forward-looking which then flattens the New Keynesian Phillips Curve (in the inflation-marginal costs space). Therefore, in order to reduce inflation by a given amount, the central bank needs to contract output by more, which in turn requires a more aggressive systematic response to inflation. Figure 1 shows how the indeterminacy region expands to the right as we consider higher steady-state inflation rates. Real wage rigidity partially undoes this effect and the minimum responsiveness to inflation ψ_π required for equilibrium uniqueness decreases as γ increases. In the figure the impact of wage rigidity on indeterminacy translates into a downwardly sloping boundary. The intuition goes as follows. Assume a sudden increase in inflation expectations that usually sets off sunspot events. In the standard New Keynesian model, ruling out these self-fulfilling expectations requires the central bank to increase the nominal rate aggressively enough to drive up the real rate – the Taylor Principle. The rise in the real rate then contracts output and lowers inflation, and therefore sunspot beliefs are no longer consistent in equilibrium. With trend inflation and a flatter Phillips Curve, the central bank is required to be more aggressive to keep indeterminacy in check. However, real wage rigidity partially off-sets the effect of trend inflation on the Taylor Principle. Indeed, wage sluggishness makes real marginal costs more persistent. Thus, whenever a firm is able to re-optimize its price, it pays more attention to current conditions. In other words, with sticky wages, firms become relatively less forward-looking and the slope of New Keynesian Phillips Curve becomes steeper. As a result, the central bank does not need to respond to inflation as strongly as

[9] When constructing Figure 1, the policy rule is $\widehat{R}_t = \psi_\pi \widehat{\pi}_t$ and parameters are set at $\beta = 0.99$, $\varepsilon = 11$, $\xi = 0.75$, $\varphi = 1$, $h = 0$ and $\alpha = \chi = 0$.

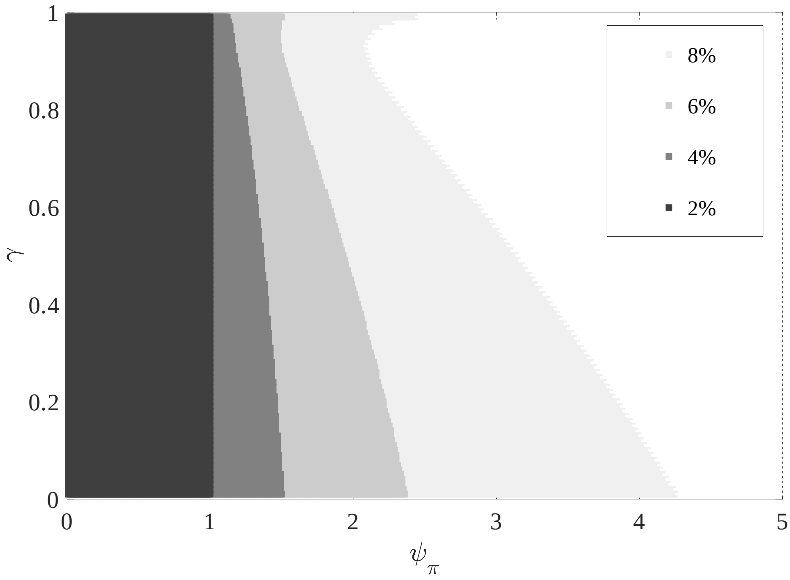

Figure 1: Indeterminacy zones (shaded)

otherwise it would have to in the absence of real wage rigidity.[10]

3 Model solution and econometric strategy

To solve the rational expectations system with indeterminacy, we follow the methodology of Lubik and Schorfheide (2003). The full set of solutions to the linear rational expectations model under indeterminacy entails the system of transition equations

$$\varrho_t = \Phi(\theta)\varrho_{t-1} + \Phi_\varepsilon(\theta, \widetilde{M})\varepsilon_t + \Phi_\zeta(\theta)\zeta_t,$$

where ϱ_t is the vector of endogenous variables, θ is the vector of the model's parameters, ε_t is the vector of fundamental shocks, and $\Phi(\theta)$, $\Phi_\varepsilon(\theta, \widetilde{M})$ and $\Phi_\zeta(\theta)$ are appropriately defined coefficient matrices.[11] Indeterminacy alters the solution in two distinct ways. First, purely extrinsic disturbances, i.e. the sunspots ζ_t, hit the economy. These sunspot shocks satisfy $\zeta_t \sim$ i.i.d. $\mathsf{N}(0, \sigma_\zeta^2)$. Second, the propagation of fundamental shocks is no longer uniquely pinned down and this multiplicity is captured by the (arbitrary) elements of $\widetilde{M}$. Following Lubik and Schorfheide (2004),

[10] If trend inflation is zero, Araújo (2009) shows that real wage rigidity does not alter the Taylor Principle.

[11] Under determinacy, the solution boils down to a VAR, i.e. $\varrho_t = \Phi^D(\theta)\varrho_{t-1} + \Phi_\varepsilon^D(\theta)\varepsilon_t$.

we replace $\widetilde{M}$ with $M^*(\theta) + M$ and set the prior mean for M equal to zero in the subsequent empirical analysis. This strategy selects $M^*(\theta)$ such that the impact responses of the endogenous variables to fundamental shocks are continuous at the boundary between the determinacy and the indeterminacy regions. Obtaining an analytical expression for the boundary in our model is infeasible. We therefore resort to a numerical procedure to find the boundary by perturbing the parameter ψ_π in the monetary policy rule.[12] In Section 6.2, we check the robustness of our results with regards to alternative perturbations.

3.1 Bayesian estimation with the Sequential Monte Carlo algorithm

We use Bayesian techniques to estimate the model parameters and to test for indeterminacy using posterior model probabilities. We follow Hirose et al. (2019) by employing the Sequential Monte Carlo algorithm of Herbst and Schorfheide (2014) to produce an accurate approximation of the posterior distribution.[13] In models like ours that contain determinacy and indeterminacy regions, the likelihood function is susceptible to exhibit multiple modes and a discontinuity at the parametric boundary. These irregularities prove to be a challenge for standard Markov chain Monte Carlo techniques (such as the Random Walk Metropolis Hastings algorithm) and these standard techniques often fail to explore the entire parameter space. The SMC algorithm tackles these problems by building a sequence of posterior distributions through steadily tempering the likelihood function. Accordingly, we are able to estimate the model simultaneously over the determinacy and indeterminacy regions.[14] The likelihood function is given by

$$p(\mathbf{X}_T|\theta_S, S) = 1\{\theta_S \in \Theta^D\}p^D(\mathbf{X}_T|\theta_D, D) + 1\{\theta_S \in \Theta^I\}p^I(\mathbf{X}_T|\theta_I, I).$$

Here, θ_S stands for the parameters of model S. Θ^D and Θ^I are the determinacy and indeterminacy regions of the parameter space, $1\{\theta_S \in \Theta^S\}$ is the indicator function

[12] See also Hirose (2014) as well as Justiniano and Primiceri (2008).

[13] Farmer et al. (2015) and Bianchi and Nicolò (2019) use alternative strategies to estimate models with indeterminacy.

[14] Lubik and Schorfheide's (2004) test for indeterminacy separately estimates the model for each parametric region. In our application, we monitor that the SMC's exploration is indeed crossing the boundary between the regions.

that equals 1 if $\theta_S \in \Theta^S$ and zero otherwise where $S \in \{D, I\}$. $\mathbf{X}_T$ denotes observations through period T and $p^D(\mathbf{X}_T|\theta_D, D)$ and $p^I(\mathbf{X}_T|\theta_I, I)$ are the likelihood functions under determinacy and indeterminacy. The SMC algorithm constructs a particle approximation of the posterior distribution by building a sequence of tempered posteriors defined as

$$\Pi_n(\theta_S) = \frac{[p(\mathbf{X}_T|\theta_S, S)]^{\phi_n} p(\theta_S|S)}{\int_{\theta_S} [p(\mathbf{X}_T|\theta_S, S)]^{\phi_n} p(\theta_S|S) d\theta_S}$$

with $p(\mathbf{X}_T|\theta_S, S)$ denoting the likelihood function, $p(\theta_S|S)$ the prior density, and ϕ_n the tempering schedule that slowly increases from zero to one determined by

$$\phi_n = \left(\frac{n-1}{N_\phi - 1}\right)^\delta \quad , \quad n = 1, ..., \ N_\phi$$

where δ controls the shape of the tempering schedule. The algorithm generates weighted draws from the sequence of posteriors $\{\Pi_n(\theta)\}_{n=1}^{N_\phi}$, where N_ϕ is the number of stages. At any stage, the posterior distribution is represented by a swarm of particles $\left\{\theta_n^i, W_n^i\right\}_{i=1}^N$, where W_n^i is the weight associated with draw θ_n^i and N denotes the number of particles. The algorithm involves three main steps. First, in the *correction* step, the particles are re-weighted to reflect the posterior density in iteration n. Next, in the *selection* step, any particle degeneracy is eliminated by resampling the particles. Liu and Chen (1998) propose, as a rule-of-thumb measure of this degeneracy, to use the reciprocal of the uncentered variance of the particles, called the effective sample size (ESS). We use systematic resampling whenever $ESS < \frac{N}{2}$. Finally, in the *mutation* step, the particles are propagated forward using a Markov transition kernel to adapt to the current bridge density by using one step of a single-block Random Walk Metropolis Hastings algorithm. In the first stage, i.e. when $n = 1$, ϕ_1 is zero and so the prior density serves as an efficient proposal density for $\Pi_1(\theta)$. Therefore, the algorithm is initialized by drawing the initial particles from the prior. The idea is that the density of $\Pi_n(\theta)$ may be a good proposal density for $\Pi_{n+1}(\theta)$. In our estimation, the tuning parameters N, N_ϕ and δ are fixed *ex ante*. We use $N = 10000$ particles and $N_\phi = 200$ stages and set δ at 2 following Herbst and Schorfheide (2015).

3.2 Calibration

We calibrate a subset of the model parameters to avoid identification issues. The discount factor β is set to 0.99, the steady state markup at ten percent, i.e. $\varepsilon = 11$, and the inverse of the labor-supply elasticity to one. Following the computations in Blanchard and Galí (2010), we calibrate the shares of oil in production and consumption to $\alpha = 0.015$ and $\chi = 0.023$ for the pre-Volcker era and $\alpha = 0.012$ and $\chi = 0.017$ for the Great Moderation period. The autoregressive parameter of the commodity price shock is fixed at $\rho_s = 0.995$ to model the commodity price being very close to a random walk (as in the data) yet retaining stationarity (Blanchard and Riggi, 2013).

3.3 Prior distributions

We estimate all remaining parameters. The specifications of the prior distributions are summarized in Table 1 and are in line with Smets and Wouters (2007) and Hirose et al. (2019). The prior for the parameter determining the central bank's responsiveness to inflation ψ_π follows a gamma distribution centred at 1.10 with a standard deviation of 0.50, while the response coefficients to both the output gap and output growth are centred at 0.125 with standard deviation 0.10. We use Beta distributions for the degree of interest rate smoothing ρ_R, the weight on headline inflation in the Taylor rule τ, the Calvo probability ξ, the real wage rigidity γ, the habit persistence in consumption h, as well as the persistence of discount factor and labor supply shocks, ρ_d and ρ_ν. For the standard deviations of the innovations, the priors for all but one follow an inverse-gamma distribution with mean 0.50 and standard deviation 0.20. The exception is the standard deviation of the oil price shocks. We center its prior distribution at 5.00 with a standard deviation of 2.00 to account for the higher volatility of these disturbances.[15] For each element of M, the vector of parameters that arises in the solution under indeterminacy, we follow Lubik and Schorfheide (2004) and use a standard normal prior. Our choice of priors leads to a prior predictive probability of determinacy of 0.51 and indicates no prior bias toward either determinacy or indeterminacy.

[15] The inverse gamma priors are of the form $p(\sigma|\upsilon,\varsigma) \propto \sigma^{-\upsilon-1} e^{-\frac{\upsilon\varsigma^2}{2\sigma^2}}$ where $\nu = 4$ and $\varsigma = 0.38$ for all shocks but commodity prices. For commodity price shocks $\varsigma = 3.81$.

3.4 Data

We estimate the model using quarterly observations on six aggregate U.S. variables. The vector of observables X_t contains the quarterly growth rates of real per-capita GDP (*GDP*), the consumer price index (*CPI*), the core consumer price index (*CoreCPI*), two measures of real wages and the level of the Federal Funds rate expressed in percent on a quarterly basis (*FFR*). Justiniano et al. (2013) find that most high frequency variations of the wage series are measurement errors and argue that ignoring this fact may lead to erroneous inference. We follow their approach by matching the model's real wage variable to two measures of hourly labor income, allowing for errors in their measurement, along the lines of Boivin and Giannoni (2006).[16] Matching the model's wage to two measures of the return to labor improves the ability to isolate the high frequency idiosyncrasies specific to each series, from a common component that is more likely to represent genuine macroeconomic forces. Wage data are *hourly compensation for the Nonfarm Business sector for all persons* (*NHC*) and *average hourly earnings of production and non-supervisory employees* (*HE*). We deflate both indicators by the CPI to obtain measures for real wages. Then the measurement equation is

$$X_t = \begin{bmatrix} 100\Delta\log GDP_t \\ 100\Delta\log CPI_t \\ 100\Delta\log CoreCPI_t \\ FFR_t \\ 100\Delta\log(NHC_t/CPI_t) \\ 100\Delta\log(HE_t/CPI_t) \end{bmatrix} = \begin{bmatrix} g^* \\ \pi^* \\ \pi^* \\ R^* \\ g^* \\ g^* \end{bmatrix} + \begin{bmatrix} \mathbf{I}_4 & \underset{4\times 2}{\mathbf{O}} \\ \underset{2\times 4}{\mathbf{O}} & \mathbf{\Lambda} \end{bmatrix} \begin{bmatrix} \widehat{g}_{y,t} \\ \widehat{\pi}_{c,t} \\ \widehat{\pi}_{q,t} \\ \widehat{R}_t \\ \widehat{g}_{w,t} \\ \widehat{g}_{w,t} \end{bmatrix} + \begin{bmatrix} \underset{4\times 1}{\mathbf{0}} \\ \mathbf{e}_t \end{bmatrix}$$

where $g^* = 100(\overline{g} - 1)$ is the steady-state net quarterly growth rate of output, $\pi^* = 100(\overline{\pi} - 1)$ is the steady-state net quarterly rate of inflation and $R^* = 100(\overline{R} - 1)$ stands for the steady-state net quarterly nominal rate of interest. Furthermore, $\widehat{g}_{y,t}$ denotes the growth rate of output, $\widehat{\pi}_{c,t}$ is consumer price inflation, $\widehat{\pi}_{q,t}$ is core consumer price inflation, $\widehat{g}_{w,t}$ is the growth rate of real wages and $\widehat{R}_t$ denotes the nominal interest rate. Hatted variables stand for log deviations from the steady state. $\mathbf{\Lambda} = diag(1, \lambda)$ is a 2×2 diagonal matrix of factor loadings relating the latent model concept of real wage growth to the two indicators and $\mathbf{e}_t = [e_{NHC,t}, e_{HE,t}]' \sim i.i.d.(\mathbf{0}, \mathbf{\Sigma})$ is a vector of

[16] See also Doko Tchatoka et al. (2017).

serially and mutually uncorrelated indicator-specific measurement errors, with $\mathbf{\Sigma} = diag(\sigma^2_{NHC}, \sigma^2_{HE})$. We jointly estimate the parameters $(\mathbf{\Lambda}, \mathbf{\Sigma})$ of the measurement equation along with the structural parameters. Our prior distributions for the loadings and measurement errors are $\lambda \sim N(1.00, 0.50)$ and $\sigma^2_{NHC}, \sigma^2_{HE} \sim IG(0.10, 0.20)$. The estimation is conducted over two sample periods: 1966:I to 1979:II and 1984:I to 2008:II. This separation aligns with the monetary policy literature as it looks at the pre-Volcker and the Great Moderation periods individually. We exclude the years of the Volcker disinflation as in Lubik and Schorfheide (2004). We do not demean or detrend any series.

4 Was U.S. monetary policy destabilizing in the 1970s?

From the exclusive perspective of (in)determinacy, we find that the answer is no. Table 2 reports the marginal data density of our model and the posterior probability of determinacy for each sample period.[17] The probability of determinacy is calculated as the fraction of draws, in the final stage of the SMC algorithm, that generate a unique equilibrium. The main result of our paper is that pre-Volcker monetary policy did not generate indeterminacy. A unique equilibrium prevailed in the turbulent 1970s as well as during the Great Moderation. In each episode, the posterior distribution puts all its mass in the determinacy region. This finding differs strikingly from Lubik and Schorfheide (2004), Hirose et al. (2019) and Nicolò (2019).

Figure 2 plots the evolution of the posterior probability of determinacy across the 200 stages of the SMC algorithm for the pre-Volcker period.[18] As the particles are re-weighted and their values modified at each stage, the tempering of the likelihood function gradually moves the approximation of the posterior distribution away from its prior form towards its final shape, which lies entirely in the determinacy region.

[17] The SMC algorithm delivers a numerical appoximation of the marginal data density as a by-product in the correction step (see Herbst and Schorfheide, 2015).

[18] Note that in the first stage, the candidate posterior probability of determinacy is close to 0.5, in line with our priors such that the indeterminacy test is a-priori unbiased.

Table 1: Prior Distributions and Posterior Parameter Estimates

Name	Density	Prior Mean (std. dev.)	Posterior Mean (Pre-79) [90% interval]	Posterior Mean (Post-84) [90% interval]
ψ_π	Gamma	1.10 (0.50)	1.51 [1.25,1.78]	3.09 [2.50,3.66]
ψ_x	Gamma	0.125 (0.10)	0.03 [0.00,0.07]	0.11 [0.03,0.20]
ψ_g	Gamma	0.125 (0.10)	0.33 [0.10,0.53]	0.62 [0.38,0.82]
ρ_R	Beta	0.50 (0.20)	0.68 [0.59,0.78]	0.73 [0.65,0.78]
τ	Beta	0.50 (0.20)	0.58 [0.32,0.84]	0.14 [0.05,0.23]
π^*	Normal	1.00 (0.50)	1.37 [1.07,1.64]	0.97 [0.81,1.11]
R^*	Gamma	1.50 (0.25)	1.53 [1.19,1.85]	1.46 [1.24,1.71]
g^*	Normal	0.50 (0.10)	0.45 [0.34,0.57]	0.17 [0.11,0.26]
ξ	Beta	0.50 (0.05)	0.60 [0.53,0.66]	0.61 [0.54,0.67]
γ	Beta	0.50 (0.20)	0.89 [0.83,0.94]	0.46 [0.26,0.63]
h	Beta	0.50 (0.10)	0.38 [0.28,0.50]	0.24 [0.16,0.33]
ρ_d	Beta	0.70 (0.10)	0.76 [0.66,0.86]	0.84 [0.78,0.90]
ρ_ν	Beta	0.70 (0.10)	0.86 [0.74,0.97]	0.99 [0.97,0.99]
σ_s	Inv-Gamma	5.00 (2.00)	17.31 [14.60,20.00]	20.14 [17.79,22.31]
σ_g	Inv-Gamma	0.50 (0.20)	0.49 [0.35,0.64]	0.43 [0.31,0.54]
σ_r	Inv-Gamma	0.50 (0.20)	0.30 [0.25,0.36]	0.17 [0.15,0.20]
σ_d	Inv-Gamma	0.50 (0.20)	1.84 [1.33,2.37]	1.21 [0.90,1.47]
σ_ν	Inv-Gamma	0.50 (0.20)	0.38 [0.25,0.49]	0.74 [0.53,0.98]
σ_ζ	Inv-Gamma	0.50 (0.20)	0.44 [0.21,0.68]	0.47 [0.22,0.73]
$M_{s,\zeta}$	Normal	0.00 (1.00)	-0.01 [-1.55,1.67]	-0.10 [-1.80,1.50]
$M_{g,\zeta}$	Normal	0.00 (1.00)	0.00 [-1.54,1.68]	-0.11 [-1.73,1.39]
$M_{r,\zeta}$	Normal	0.00 (1.00)	0.01 [-1.57,1.62]	0.03 [-1.59,1.60]
$M_{d,\zeta}$	Normal	0.00 (1.00)	0.08 [-1.50,1.74]	0.06 [-1.49,1.70]
$M_{\nu,\zeta}$	Normal	0.00 (1.00)	0.01 [-1.60,1.64]	0.06 [-1.48,1.70]
λ	Normal	1.00 (0.50)	1.05 [0.66,1.43]	0.30 [0.16,0.43]
σ^2_{NHC}	Inv-Gamma	0.10 (0.20)	0.36 [0.19,0.51]	0.66 [0.55,0.77]
σ^2_{HE}	Inv-Gamma	0.10 (0.20)	0.47 [0.33,0.63]	0.38 [0.32,0.44]

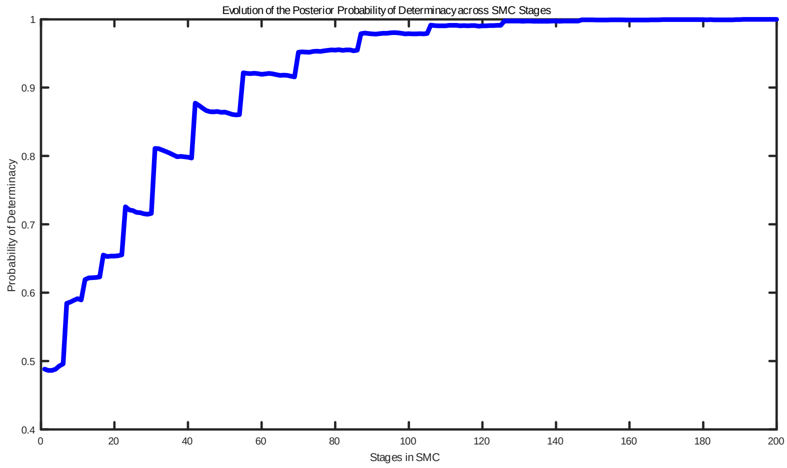

Figure 2: Evolution of the Posterior Probability of Determinacy across SMC stages for the 1966:I to 1979:II period.

4.1 What drove determinacy?

Our diagnosis of the Seventies may be surprising. Accordingly, it is natural to ask what drives it? To shed light on this issue, let us start by looking at the posterior estimates of the structural parameters shown in Table 1. The fourth column in the Table reports the posterior means and 90 percent highest posterior density intervals for the pre-Volcker period, based on 10000 particles from the final importance sampling step. Let us focus on the monetary policy parameters first. Our estimate of the annualized steady-state inflation rate for that period is around 5.5 percent, which is close to the median estimate of trend inflation obtained by Ascari and Sbordone (2014). The response to inflation was active, i.e. greater than one, which echoes Orphanides (2004), Nakov and Pescatori (2010) and, most closely related to us, Hirose et al. (2019). However, our estimates of the central bank's responses to the output gap and output growth differ from Hirose et al. (2019). We find that the Federal Reserve was barely reacting to output gap fluctuations and was, instead, responding strongly to output growth. As shown by Coibion and Gorodnichenko (2011), these two features tend to stabilize GNK economies. In fact, the combination of a strong response to inflation together with an insignificant reaction to the output gap holds the key to our result that the US economy was likely in the determinacy region even

Table 2: Determinacy versus Indeterminacy

	Log-data density	Probability of determinacy
1966:I-1979:II	-279.27	1
1984:I-2008:II	-275.71	1

Notes: According to the prior distributions, the probability of determinacy is 0.51.

during the 1970s.

To connect with existing work and better understand which features of our econometric strategy lead to our interpretation of the Great Inflation, we now consider a sequence of special cases of our empirical model and report the findings in Table 3 (marginal data density and probability of determinacy) and Table 4 (parameter estimates). To begin with, we shut down oil in the model by calibrating the shares of oil in consumption and production to zero ($\alpha = \chi = 0$). The model then features only one concept of inflation and we therefore set the weight of headline inflation in the policy rule equal to one ($\tau = 1$). We further set the degree of real wage rigidity to zero ($\gamma = 0$) and turn off the labor supply disturbances. This artificial economy thus boils down to a simple GNK model with positive trend inflation and three fundamental shocks (discount factor, technology and monetary policy) similar to Hirose et al. (2019). We estimate this specification using only three standard observables: output growth, the Federal Funds rate and inflation (Headline CPI). The first row in Table 3 confirms that this estimation favors indeterminacy in the pre-Volcker period in line with Hirose et al. (2019).[19]

Having bridged the gap with existing studies, we now sequentially add one feature at a time until we end up again with our original state-space model. To begin with, we introduce real wage rigidity by specifying an agnostic prior distribution for γ while we still estimate this model with only three observables.[20] In the third column of Table 4, we see that the posterior of γ is similar to the prior, indicating that the

[19] We obtain a somewhat lower probability of indeterminacy than Hirose et al. (2019). This slight difference is explained by the fact that our model features homogenous labor as in Ascari and Sbordone (2014), while Hirose et al. (2019) assume firm-specific labor. Moreover, they use a different measure of inflation (GDP deflator) to estimate their model.

[20] As prior for γ, we employ a Beta distribution with a mean of 0.5 and standard deviation of 0.2.

Table 3: Determinacy versus Indeterminacy (1966:I - 1979:II)

	Log density	Prob. of det.
GNK, 3 obs $(g_{y,t}, R_t, \pi_{c,t})$ $[\alpha, \chi, \gamma = 0; \tau = 1]$	-118.02	0.07
GNK, 3 obs $(g_{y,t}, R_t, \pi_{c,t})$ $[\alpha, \chi = 0; \tau = 1]$	-118.90	0.20
GNK with Oil, 3 obs $(g_{y,t}, R_t, \pi_{c,t})$ $[\tau = 1]$	-118.22	0
GNK with Oil, 4 obs $(g_{y,t}, R_t, \pi_{c,t}, \pi_{q,t})$	-157.12	0.80
GNK with Oil, 6 obs $\left(g_{y,t}, R_t, \pi_{c,t}, \pi_{q,t}, \Delta w_t^{NHC}, \Delta w_t^{HE}\right)$	-279.27	1

Notes: The state-space models are (from top to bottom): i) Basic GNK model estimated with three observables; ii) GNK model featuring wage rigidity estimated with three observables; iii) GNK model with oil and wage rigidity estimated with three observables; iv) GNK with oil and wage rigidity estimated with four observables (i.e. two inflation measures); v) GNK with oil and wage rigidity estimated with six observables (i.e. two wage series). Parameters in square brackets are calibrated. "obs" denotes the number of observables which are indicated in parentheses.

degree of real wage rigidity may not be properly identified. The posterior probability of determinacy increases slightly to 20 percent (second row of Table 3). This finding is consistent with our previous discussion regarding how real wage rigidity affects the determinacy region (see Figure 1).

We then turn on oil by resetting the values of α and χ to their benchmark calibrations. This setup gives us a New Keynesian model with sluggish wages and micro-founded cost-push shocks, features that are reminiscent of the environment in the 1970s, yet are missing in existing empirical investigations on indeterminacy. We also switch on labor supply disturbances. To disentangle the respective contributions of shocks, frictions and observables, we continue, for now, to use only three observables in the estimation (hence we calibrate τ at one). The third row of Table 3 shows that the data now unambiguously prefers indeterminacy for the pre-Volcker period. The decline in the posterior probability of determinacy reflects the lower wage rigidity that is obtained when we include persistent labor supply shocks. Looking at the fourth column in Table 4, we observe that the posterior standard deviation of oil price shocks σ_s is virtually indistinguishable from the prior suggesting identification issues:

using only one inflation measure does not provide sufficient information to pin down commodity price shocks.

Hence, we next simultaneously treat both headline and core inflation as observables and our dataset now includes four variables. This step enables a tight identification of oil-price shocks or more generally commodity price shocks (see equation 1). We are now also in a position to estimate the weight τ in the policy rule as arguably it can now be identified. The fourth row of Table 3 shows that the probability of determinacy rises considerably. Moreover, as anticipated, the innovation to the oil-price shock σ_s is now well identified: the posterior mean is one order of magnitude larger than the prior mean.

The last step deals with the identification of the degree of wage sluggishness γ which is a key parameter in our artificial economy. As Blanchard and Galí (2007) argue, the presence of real wage rigidity generates a trade-off between stabilizing inflation and the output gap in response to supply-side disturbances. Moreover, Blanchard and Riggi (2013) document that real wage rigidity plays a fundamental role in the propagation of oil price shocks. To sharpen the identification of this rigidity parameter, we next add the two series of real wage data, i.e. we employ all six observables to estimate the model. This final step completes our exploration by taking us back to our benchmark setup. As argued above, the pre-Volcker period is then clearly and unambiguously characterized by determinacy and a high degree of real wage rigidity.

4.2 A closer look at monetary policy parameters

Table 4 details the parameter estimates. For the GNK model estimated with three observables, the posterior mean of the central bank's response to inflation lies around one. This result is in line with Coibion and Gorodnichenko (2011) and Hirose et al (2019). When we use both headline and core inflation measures in the estimation we are able to identify the commodity price shocks and the response to inflation then turns active. Yet, that is not enough to completely rule out indeterminacy as the Taylor principle is not sufficient to guarantee a determinate equilibrium in a model with trend inflation. However, once we add wage data to our estimation, the degree

Table 4: Parameter Estimates (1966:I-1979:II)

	GNK $\gamma = 0$ 3 obs	GNK 3 obs	GNK-Oil 3 obs	GNK-Oil 4 obs	GNK-Oil 6 obs
ψ_π	0.96 [0.87,1.11]	0.96 [0.76,1.16]	0.94 [0.75,1.12]	1.16 [0.93,1.35]	1.51 [1.25,1.78]
ψ_x	0.10 [0.00,0.22]	0.14 [0.00,0.27]	0.23 [0.00,0.42]	0.15 [0.00,0.31]	0.03 [0.00,0.07]
ψ_g	0.09 [0.00,0.17]	0.11 [0.01,0.21]	0.11 [0.01,0.21]	0.14 [0.01,0.26]	0.33 [0.10,0.53]
ρ_R	0.41 [0.28,0.53]	0.44 [0.29,0.59]	0.48 [0.36,0.61]	0.50 [0.35,0.64]	0.68 [0.59,0.78]
τ	1	1	1	0.65 [0.43,0.88]	0.58 [0.32,0.84]
π^*	1.40 [1.07,1.72]	1.43 [1.14,1.71]	1.34 [1.00,1.69]	1.38 [1.09,1.70]	1.37 [1.07,1.64]
R^*	1.54 [1.21,1.85]	1.57 [1.30,1.83]	1.50 [1.19,1.79]	1.55 [1.23,1.84]	1.53 [1.19,1.85]
g^*	0.46 [0.31,0.62]	0.49 [0.33,0.65]	0.51 [0.36,0.65]	0.51 [0.37,0.65]	0.45 [0.34,0.57]
ξ	0.50 [0.43,0.60]	0.50 [0.42,0.59]	0.54 [0.46,0.61]	0.57 [0.48,0.65]	0.60 [0.53,0.66]
γ	0	0.51 [0.17,0.90]	0.33 [0.07,0.60]	0.30 [0.04,0.59]	0.89 [0.83,0.94]
h	0.38 [0.27,0.48]	0.47 [0.28,0.51]	0.37 [0.27,0.49]	0.31 [0.21,0.41]	0.38 [0.28,0.50]
ρ_d	0.83 [0.73,0.92]	0.78 [0.65,0.90]	0.70 [0.54,0.86]	0.68 [0.53,0.83]	0.76 [0.66,0.86]
ρ_ν	–	–	0.69 [0.53,0.86]	0.72 [0.56,0.87]	0.86 [0.74,0.97]
σ_s	–	–	5.43 [2.12,8.45]	17.03 [14.44,19.58]	17.31 [14.60,20.00]
σ_g	1.49 [1.17,1.80]	1.57 [1.19,1.93]	1.51 [1.17,1.86]	1.26 [0.95,1.73]	0.49 [0.35,0.64]
σ_r	0.32 [0.25,0.38]	0.31 [0.24,0.38]	0.30 [0.25,0.36]	0.31 [0.24,0.38]	0.30 [0.25,0.36]
σ_d	0.96 [0.76,1.16]	0.56 [0.31,0.85]	0.40 [0.20,0.60]	0.86 [0.35,1.31]	1.84 [1.33,2.37]
σ_ν	–	–	0.36 [0.19,0.53]	0.45 [0.22,0.69]	0.38 [0.25,0.49]
σ_ζ	0.53 [0.20,0.85]	0.51 [0.20,0.82]	0.46 [0.21,0.74]	0.50 [0.20,0.82]	0.44 [0.21,0.68]
$M_{s,\zeta}$	–	–	−1.19 [−2.28,−0.46]	−0.12 [−1.40,1.58]	−0.01 [−1.55,1.67]
$M_{g,\zeta}$	0.94 [−0.76,2.28]	0.61 [−0.97,1.91]	0.78 [−0.37,1.95]	0.10 [−1.46,1.67]	0.00 [−1.54,1.68]
$M_{r,\zeta}$	0.18 [−1.29,1.68]	0.09 [−1.60,1.65]	0.39 [−1.16,2.06]	0.10 [−1.50,1.70]	0.01 [−1.57,1.62]
$M_{d,\zeta}$	0.07 [−1.69,1.75]	0.16 [−1.60,1.95]	−0.16 [−1.89,1.46]	0.02 [−1.36,1.92]	0.08 [−1.50,1.74]
$M_{\nu,\zeta}$	–	–	−0.23 [−1.82,1.52]	−0.02 [−1.62,1.56]	0.01 [−1.60,1.64]
λ	–	–	–	–	1.05 [0.66,1.43]
σ_{e_1}	–	–	–	–	0.36 [0.19,0.51]
σ_{e_2}	–	–	–	–	0.47 [0.33,0.63]

of real wage rigidity becomes significantly higher: the point estimate sits at around 0.9. Such a high degree of real wage rigidity worsens the trade-off faced by the central bank in the wake of commodity price shocks and our intuition is that the Taylor rule parameters are influenced by this policy trade-off. Our estimation reflects this as the response to inflation ψ_π turns strongly active with a posterior mean of about 1.5, while the Federal Reserve's response to the real economy changes: the mean response to the output gap ψ_x drops to only 0.03 while its response to output growth ψ_g becomes stronger (0.33). Combined, such changes to the Taylor Rule parameters push the posterior distribution toward the determinacy region of the parameter space.[21]

Figure 3 shows the posterior mean estimates of ψ_π and ψ_x for the pre-Volcker period in four different estimation setups.[22] The panel in the North West corner represents the results from the basic GNK model estimated with the usual three observables (similar to Hirose et al. 2019), while our baseline results are visible in the South East panel. In all cases, the parameters (other than ψ_π and ψ_x) are set at their posterior mean and crosses locate the posterior mean of the two policy parameters. Reminiscent of Ascari and Ropele (2009) and Coibion and Gorodnichenko (2011), the areas displayed in Figure 3 imply that responding to the output gap is destabilizing. The North West panel reports results that are in line with the substantial uncertainty found in the literature about whether or not the Taylor principle was satisfied in the pre-Volcker era (Clarida et al. 2000; Orphanides 2004; Lubik and Schorfheide 2004; Coibion and Gorodnichenko 2011; Hirose et al. 2017). Instead, in the South East panel which involves estimation with all six observables, the combination of a clearly active ψ_π and a virtually zero ψ_x puts the economy unambiguously into the determinacy region.[23]

To summarize so far, through the lens of our model, we do not find support for the thesis that the Federal Reserve failed to respond aggressively to inflation. Once the estimation uses wage data, a significant degree of real wage rigidity arises for the

[21] Hirose et al. (2017) report a smaller estimate for ψ_π and a larger estimate for ψ_x implying indeterminacy, which resonates with the estimates we obtain in cases where commodity price shocks and wage rigidity are either absent or not identified properly.

[22] We report specifications i), iii), iv) and v) from Table 3.

[23] The non-reaction to the output gap is compensated by a marked response to output growth which is also stabilizing (see Coibion and Gorodnichenko, 2011, Orphanides and Williams 2006, and Walsh, 2003).

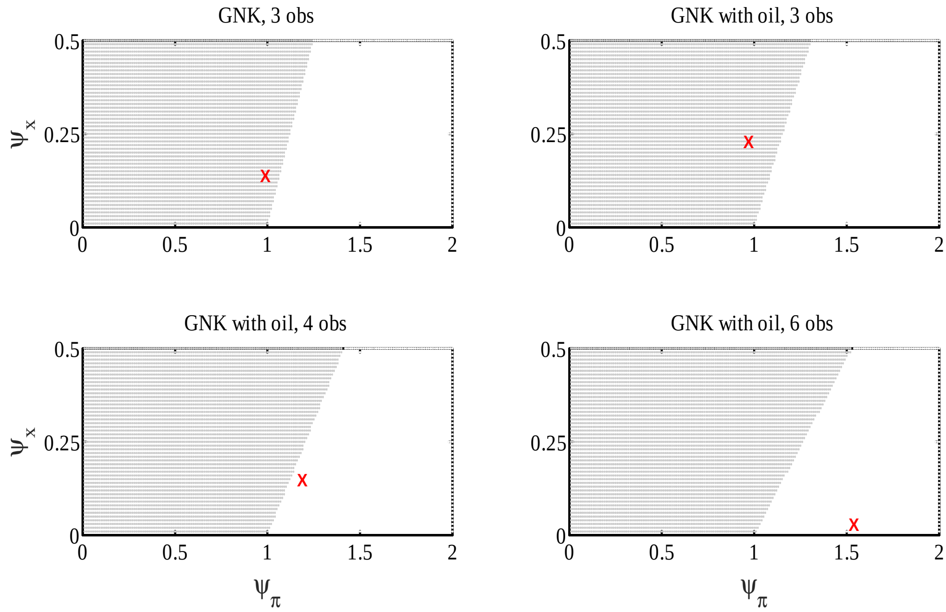

Figure 3: Indeterminacy regions in the $\psi_\pi - \psi_x$ space.

1970s. This rigidity breaks down the divine coincidence and enables commodity price shocks to create a steep trade-off between stabilizing inflation and the output gap (Blanchard and Gali, 2007 and Blanchard and Gali, 2010). This trade-off considerably affects our estimates of the systematic component of monetary policy. As a result, indeterminacy of the system disappears as an explanation of the Great Inflation.

4.3 Identifying cost-push shocks and the output gap

Here we address two aspects pertaining to the estimation. First, Figure 4 underlines how identification of oil-price shocks is achieved when using both headline and core inflation data in the estimation. It displays the smoothed estimates of the real commodity prices, shown here as the quarterly growth rate in deviations from the steady state (i.e. commodity price inflation). When the estimation employs only three observables. i.e. only one series for inflation, the estimated commodity price shows no spike around 1973-74 and 1979. That is, commodity price shocks are not identified. However, once the estimation utilizes both inflation data (i.e. the case of four observables), commodity price shocks become evident as spikes in both periods. The smoothed estimates are exactly the same for estimations that use wage data –

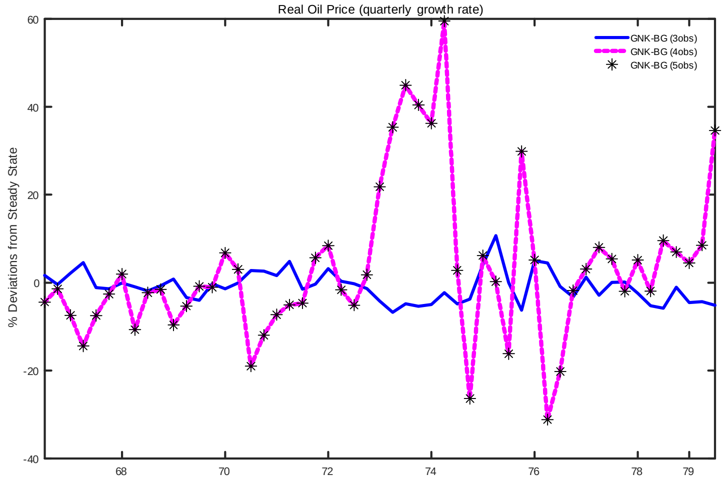

Figure 4: Identification of commodity price shocks

they virtually overlap in the graph. This result indicates that the estimation requires headline and core inflation only to exactly pin down the commodity price shocks irrespective of the other observables used. In fact, that is exactly what one expects from equation (1) as it relates headline, core and commodity price inflation in the model. Yet, while the smoothed sequence predicts big shocks being present in early 1973, oil prices only began to take off at the beginning of 1974. This is explained by the increases in industrial commodity prices that preceded the oil price shocks (see Barsky and Kilian, 2001, and Bernanke et al., 1997) and is linked to our identification using core and headline inflation. In the robustness checks section below, we show that our results carry over when we directly treat the real price of oil as an observable.

Second, as the output gap takes on a central role in the model's interpretation of the economy, it is important to verify whether the estimated series of the latent model-consistent output gap bears any resemblance with popular empirical counterparts. Figure 5 compares our smoothed estimates of the model's output gap against the CBO output gap.[24] We see that for all estimations that do not include wage data, the estimated output gap series is basically a flat line that has no resemblance to the CBO's measure. Phrased alternatively, while the joint use of core and headline

[24]We do not use the CBO output gap in any of our estimations. Hence, the comparison serves as an external validation of our results.

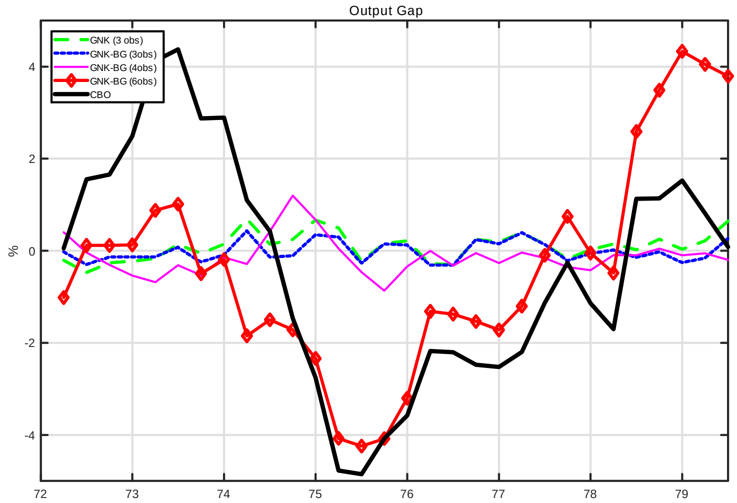

Figure 5: Output gaps *vis-à-vis* CBO.

inflation series exactly identifies commodity price shocks, this feature of our econometric strategy, in isolation, falls short of identifying properly the output gap. Yet, once information on wages is included and the propagation dynamics of oil price shocks set, the smoothed series of the output gap becomes highly correlated with the CBO's measure (see Table 5). Then, and only then, can we unequivocally rule out indeterminacy for the Seventies.

Table 5: Output Gaps: GNK Model vs CBO

	Standard Deviation	Correlation with CBO
CBO Output Gap	2.53	1.00
GNK, 3 obs	0.30	-0.23
GNK with Oil, 3 obs	0.22	-0.31
GNK with Oil, 4 obs	0.40	-0.14
GNK with Oil, 6 obs	2.31	0.66

4.4 Real wage rigidity and the trade-off between inflation and the output gap

The central bank's trade-off between output gap and inflation stabilization is at the center of our story. Here we want to investigate how important real wage rigidity is in generating this negative comovement between inflation and the output gap conditional on commodity price shocks? Figure 6 plots impulse response functions for headline inflation, core inflation, the output gap and price dispersion to a ten percent commodity price shock. To better sift out the role of slow wage adjustments, each plot considers three calibrations of the rigidity parameter: $\gamma = 0$, i.e the benchmark case of a Walrasian labor market with perfectly flexible real wage, $\gamma = 0.6$ corresponding roughly, according to our estimates, to the upper bound for the degree of real wage rigidity in the post-Volcker era, and $\gamma = 0.9$ which is in line with the posterior mean of γ in the pre-Volcker period.[25]

In the presence of complete real wage flexibility, $\gamma = 0$, headline inflation increases (mechanically with oil prices) while core inflation and price dispersion decrease and the output gap hardly moves at all. With flexible wages, an increase in the real price of oil reduces the real wage through a wealth effect on labor supply, and consequently lowers marginal costs (Blanchard and Gali 2010). As a result, both desired prices and price dispersion fall. On the other hand, for higher levels of real wage stickiness (e.g. $\gamma = 0.9$ in Figure 6), output and inflation negatively comove and policy-makers face a trade-off between output gap and inflation (both headline and core) stabilization. With real wages being rigid, an increase in the real price of oil results in an increase in the firms' marginal costs as well as desired prices and core inflation. Also, price dispersion increases which leads to further endogenous rise in inflation. Using the terminology often used by central banks, higher real wage rigidity is associated with strong "second-round" effects. That is, faced with similar initial increase in the CPI, dubbed the "first-round" effects, and for a given employment, workers ask for and obtain increases in nominal wages, which then lead to higher marginal costs for firms and therefore higher prices, thereby confronting the central bank with a worse trade-

[25] The structural parameters as well as the policy parameters are calibrated to their estimated posterior mean values for the pre-1979 period.

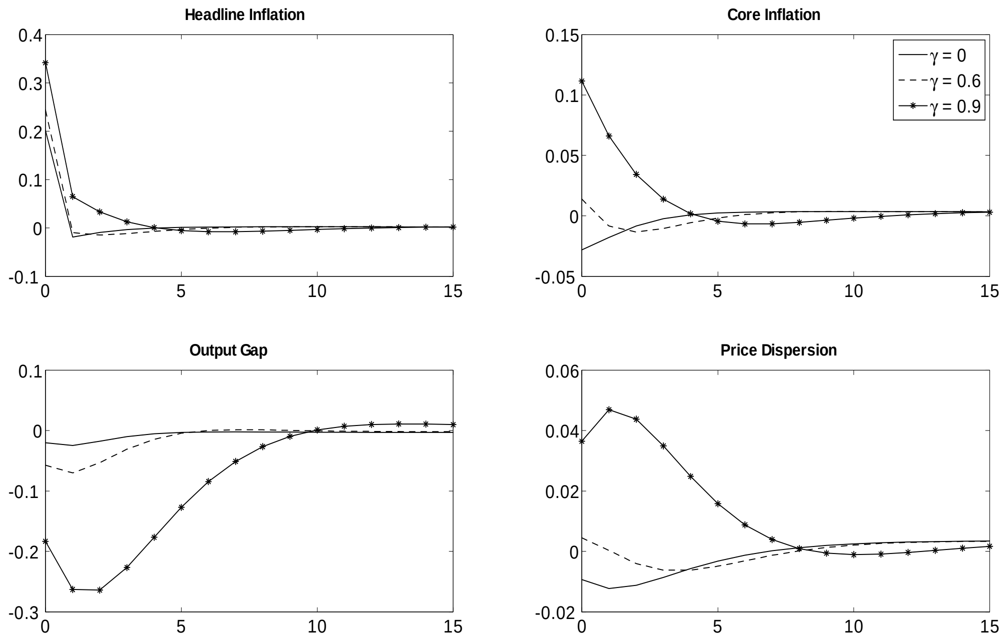

Figure 6: Model-based impulse response functions to a positive commodity price shock

off between activity and inflation.

5 What caused the Great Moderation?

Above we have established that one can rule out indeterminacy as a source of instability during the Great Inflation. Does our result mean that monetary policy in the 1970s was blameless? To answer this question, we now investigate whether monetary policy in the 1970s might have been destabilizing in a broader sense. We do this by going through various counterfactual exercises designed to disentangle the role played by monetary policy and oil price shocks in driving the Great Moderation.

5.1 Changes in monetary policy and the Great Moderation

We begin by comparing the parameter estimates across the the pre-Volcker and the Great Moderation periods, shown in the last two columns of Table 1. Let us start with the Federal Reserve's interest rate rule's coefficients. The key findings are that, across the two periods, the policy response to inflation ψ_π and to output growth

ψ_g doubled while trend inflation fell. These findings align with Coibion and Gorodnichenko (2011). In comparison, the reaction to the output gap ψ_x stayed relatively muted. Also, the Federal Reserve moved its focus away from responding to headline inflation toward core inflation during the Great Moderation. This greater relevance of core inflation in the formulation of monetary policy echoes Mehra and Sawhney (2010).[26] The posterior mean of the standard deviation of monetary policy shocks declined from 0.30 to 0.17. In that sense monetary policy became less erratic (more rule-based) during the Great Moderation period.

Turning briefly to the other parameters, we see that the degree of real wage rigidity γ fell substantially, from 0.89 to 0.46. This finding parallels Blanchard and Gali (2010) and Blanchard and Riggi (2013) and can be interpreted as capturing the decline in unions bargaining power.[27] Lastly, the shocks. The size of commodity price shocks and labor supply shocks increased across the two periods. As in Bjørnland et al. (2018), this rise in the magnitude of commodity price shocks could reflect more frequent episodes of high oil price volatility in the post-1984 period. The variance of discount factor shocks declined materially.

What is the estimated model's ability to capture the Great Moderation, in particular the marked decline in macroeconomic volatility since the mid-1980s? Table 6 summarizes the model's implications for the standard deviation of inflation (both headline and core) and output growth – evaluated at the posterior mean – along with U.S. data. The estimated model replicates the observed volatility drops.[28] Despite the fact that our model is relatively small compared to the models of Smets and Wouters (2007) or Justiniano and Primiceri (2008), its good performance at replicating the observed reduction in macroeconomic volatility across the two periods is reassuring and substantiates the empirical plausibility of our estimation results.

Our ultimate goal in this paper is to assess the performance of U.S. monetary

[26] For a related analysis pertaining to the Taylor-Bernanke controversy regarding the conduct of monetary policy in the aftermath of the 2001 recession, see Doko Tchatoka et al. (2017). Note that they abstract from trend inflation.

[27] Blanchard and Riggi (2013) document an even larger decline in γ. They employ a limited-information impulse response matching estimation technique while we perform a full-information Bayesian estimation with multiple shocks.

[28] Our model overestimates the volatility of aggregate variables in both periods. However, the same tendency also plagues medium-scale models (Smets and Wouters, 2007).

Table 6: The Great Moderation

	Standard Deviation				Percent Change Between Periods	
	1966:I-1979:II		1984:I-2008:II			
	Data	Model	Data	Model	Data	Model
Headline Inflation	0.68	1.04	0.38	0.45	-44%	-56%
Core Inflation	0.60	0.88	0.28	0.26	-53%	-70%
Output Growth	1.01	1.14	0.53	0.63	-48%	-45%

policy during the Great Inflation episode. To put our verdict of the Federal Reserve's actions during the 1970's in perspective, we now consider the role of monetary policy in driving the Great Moderation. Our baseline model nests two popular explanations for the Great Moderation - good policy and good luck. To disentangle the respective contributions of changes in shocks, policy and structural factors across the two periods, we conduct a series of counterfactual exercises similar in spirit to Cogley et al. (2010) and Nakov and Pescatori (2010) among others. We divide the counterfactuals into two categories. First, we combine the parameters pertaining to monetary policy, i.e. ψ_π, ψ_x, ψ_g, $\rho_R, \tau, \pi^*, \sigma_r$, from the post-1984 sub-sample with the private sector and shock parameters of the first sub-sample. We call this case *Policy 2, Private 1.* In the second category, we combine the private sector and the shock parameters of the post-1984 sample with the policy parameters of the first. We denote this case by *Policy 1, Private 2.* Table 7 reports the results as percentage deviations with respect to our baseline model for the pre-Volcker period.

A substantial decline in inflation volatility is driven by monetary policy. In particular, a more aggressive policy reaction to inflation alone, via the post-1984 estimate of ψ_π, would have resulted in 39 percent and 57 percent declines of the standard deviations of headline and core inflation respectively. Other dimensions of better monetary policy, such as the decline in trend inflation, i.e. the Federal Reserve's inflation target, or the smaller standard deviation of monetary policy disturbances, have played a comparatively negligible role in the observed decline in inflation volatility. The cournterfactual labelled *"Policy 1, Private 2"* suggests that other factors, beyond the changes in monetary policy, also contributed to the reduction in inflation volatility. Among these other factors, the fall in the degree of real wage sluggishness played a major role.

Turning our attention to the observed dampening in the volatility of output growth, our counterfactual experiments suggest that this phenomenon is not related to the evolution in the Federal Reserve's conduct of monetary policy but is, to a large extent, explained by the decline in real wage rigidity. This finding parallels Blanchard and Gali (2010) who argue that lower real wage rigidity in the 2000s has changed the propagation of oil price shocks and has improved the inflation - output gap trade-off. Finally, favourable shifts in the distribution of aggregate demand shocks (discount factor shocks) also contributed to the moderation in business cycle fluctuations. This finding echoes the "good luck" narrative. [29]

The bottom line is that a combination of factors account for the Great Moderation. Better monetary policy (mainly in terms of more aggressive response to inflation) as well as non-policy factors such as the decline in real wage rigidity and smaller aggregate demand shocks, all played their part in bringing about the era of macroeconomic stability after 1984. An important implication is that the conduct of monetary policy during the 1970s is not unblemish: even though the Federal Reserve did not trigger indeterminacy, a more aggressive response to inflation in the pre-Volcker period would have resulted in significantly lower inflation volatility.

5.2 Oil and the Great Moderation

What is the role of oil in the Great Moderation? Table 1 shows that our estimated commodity price shocks have become larger after 1984, a finding we share with Leduc and Sill (2007) Bjørnland et al. (2018).[30] Since the late 1990s, the global economy has experienced oil shocks of sign and magnitude comparable to those of the 1970s. Yet, we did not experience a come-back of the Great Stagflation and business cycle

[29] The *good luck* interpretation has been advocated by Stock and Watson (2002), Primiceri (2005), Sims and Zha (2006), Smets and Wouters (2007), Justiniano and Primiceri (2008) and others.

[30] Nakov and Pescatori (2010) treat the real price of oil as observable and find that oil price shocks have become smaller in the second period. Instead, our baseline estimation uses simultaneously headline and core inflation data to back out the latent commodity price shocks. In the robsutness section, we use oil price data in the estimation and find a decline in the standard deviation of oil price shocks.

Table 7: Counterfactual standard deviations

Scenarios	Headline Inflation		Core Inflation		Output growth	
	St. Dev	% Change	St. Dev	% Change	St. Dev	% Change
Baseline	1.04	-	0.88	-	1.14	-
Policy 2, Private 1	0.75	-28%	0.51	-42%	1.04	-8%
ψ_π, ψ_x, ψ_g, ρ_R	0.70	-33%	0.49	-44%	1.08	-5%
ψ_π	0.63	-39%	0.38	-57%	1.17	+3%
π^*	1.05	+1%	0.88	0%	1.14	0%
σ_r	1.02	-2%	0.86	-2%	1.09	-4%
Policy 1, Private 2	0.72	-31%	0.56	-36%	0.78	-32%
γ , σ_d	0.65	-38%	0.51	-42%	0.62	-46%
γ	0.79	-24%	0.68	-23%	0.73	-36%

fluctuations in both output and inflation have been relatively benign. This striking difference between the two periods suggests that the propagation of oil price shocks has evolved, a view advocated by Blanchard and Gali (2010).[31] Figure 7 shows the estimated responses of headline inflation, core inflation, the Federal Funds rate and output growth for both sample periods. We see evidence of a significant change over time in the dynamic effects of commodity price shocks.We find much smaller effects on core inflation, real activity and interest rate in the second sub-sample, despite the fact that these shocks are slightly larger in size. Only the impact response of headline inflation is similar, albeit with a smaller persistence. This is intuitive since, as argued above, part of the rise in oil prices is reflected automatically in the oil component of headline inflation. Overall, our findings are consistent with the empirical evidence based on structural VARs put forth by Blanchard and Galí (2010), Blanchard and Riggi (2013), Kilian (2008, 2009) and Barsky and Kilian (2001, 2004).

To examine the conjecture of a mutation in the propagation of commodity price shocks across the two periods, we perform two counterfactual experiments. First, we combine the posterior mean estimates of the Taylor rule parameters, i.e. ψ_π, ψ_x, $\psi_{\Delta y}$, ρ_R, π^*, and τ, pertaining to the post-1984 sample period with the remaining parameter estimates of the pre-1979 period. We label this first experiment "Post-84 Policy" as it is designed to reveal the role of "better" systematic monetary policy

[31] Blanchard and Gali (2010) and Nakov and Pescatori (2010) also connect the falling shares of oil in production and consumption to the Moderation. We find that this change can explain about eight percent of the decline in headline inflation volatility.

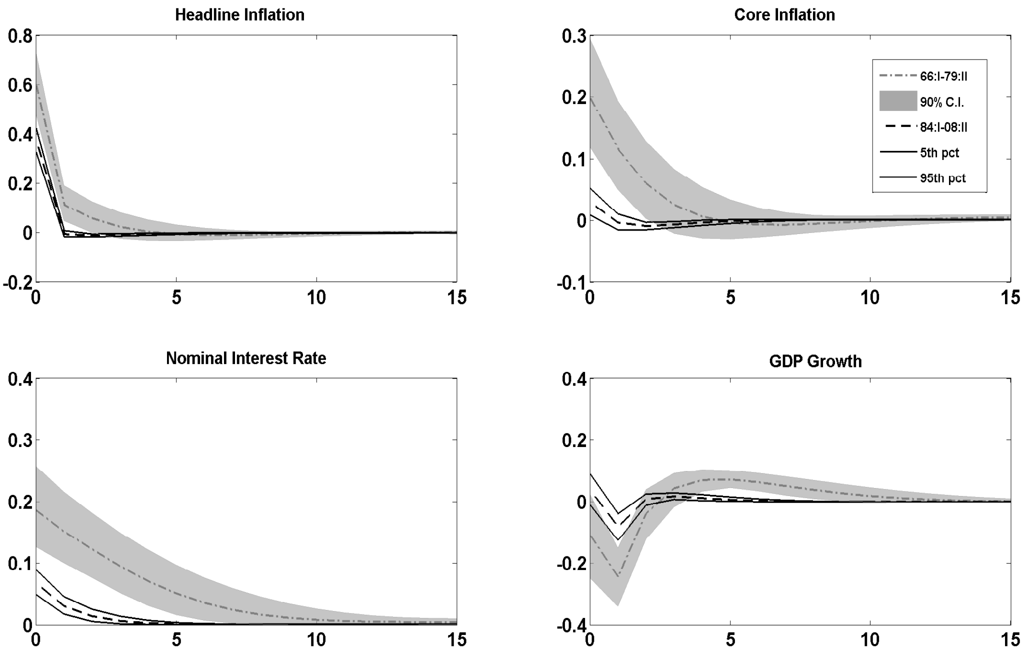

Figure 7: Bayesian impulse response functions to a positive commodity price shock

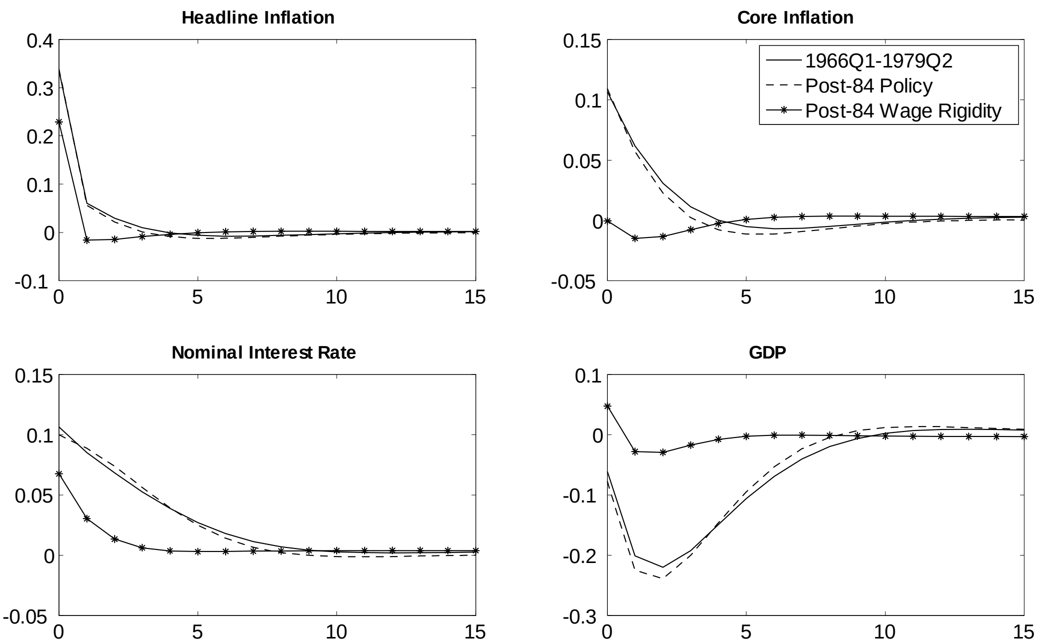

Figure 8: Counterfactual impulse response functions to a commodity price shock

in attenuating the macroeconomic consequences of cost-push shocks. Our second experiment combines the posterior mean estimates of the pre-1979 period (including the policy parameters) with the estimated (lower) real wage rigidity from the post-1984 period, labelled *"Post-84 Wage Rigidity"*. This scenario is designed to capture the role of the decline in real wage rigidity as a possible explanation. Figure 8 depicts the impulse responses to a ten percent commodity price shock under the two alternative scenarios, while calibrating the remaining parameters at their pre-1979 posterior mean estimates. We see that the subdued effects of commodity price shocks are mainly due to the decline in real wage rigidity. Our finding corroborates one of the hypotheses put forth by Blanchard and Galí (2010) and is also in line with the empirical evidence documented in Blanchard and Riggi (2013). As argued earlier, a high degree of real wage rigidity generates a steep trade-off between inflation and output gap stabilization.

6 Robustness of determinacy

We now assess the robustness of our determinacy result for the pre-Volcker period. Our checks fall into two broad categories: (i) twists to the model and (ii) twists to the econometric strategy. For each check, we re-estimate the model using the baseline observables unless otherwise speficied. Table 8 summarizes the log-data densities and the posterior probabilities of determinacy for all checks. We delegate the parameter estimates to Tables A1 and A2 in the Appendix.

6.1 Twists to the model

We start probing the robustness of our results by considering variations to the specification of the baseline model. We focus especially on the modeling of the central bank's interest-rate rule. Directions include (i) a Taylor rule that does not feature core inflation; (ii) a Taylor rule that responds to the annual (year-on-year) rates of inflation and output growth (Justiniano et al., 2013); (iii) a Taylor rule that responds to the flexible-price output gap. In addition, we also (iv) allow for indexation to past inflation in firms' price setting.

Taylor rule without core inflation Monetary policy in our baseline model follows a Taylor rule that responds to core inflation. It could be argued that allowing for a systematic reaction to core inflation is the key factor that drives our determinacy result. Namely, using a relatively smooth inflation series as an observable that enters in the Taylor rule should yield a larger estimate of ψ_π and thereby favor determinacy. We therefore set τ, the weight of headline inflation in the policy rule, equal to one so that the central bank only reacts to headline inflation and re-estimate the model. As it turns out, calibrating $\tau = 1$ has little impact on the estimated parameters and the posterior probability of determinacy stays unchanged.

Taylor rule with annual inflation and output growth Justiniano et al. (2013) propose an alternative formulation of the monetary policy rule that features systematic responses to deviations of annual inflation from the inflation target, and to deviations of annual GDP growth from its steady state level.[32] Thus, we re-estimate the model by replacing the policy rule (5) with the following formulation:

$$\frac{R_t}{\overline{R}} = \left(\frac{R_{t-1}}{\overline{R}}\right)^{\rho_R} \left(\left[\left(\frac{\left(\prod_{s=0}^{3} \pi_{c,t-s}\right)^{\frac{1}{4}}}{\overline{\pi}} \right)^{\tau} \left(\frac{\left(\prod_{s=0}^{3} \pi_{q,t-s}\right)^{\frac{1}{4}}}{\overline{\pi}} \right)^{1-\tau} \right]^{\psi_\pi} \left[\frac{Y_t}{Y_t^*}\right]^{\psi_x} \left[\frac{\left(\frac{Y_t}{Y_{t-4}}\right)^{\frac{1}{4}}}{\overline{g}} \right]^{\psi_g} \right)^{1-\rho_R} e^{\varepsilon_{R,t}}.$$

We find a stronger response to output growth in both periods, which is similar in magnitude to what Justiniano et al. (2013) report. Other than this, the determinacy result carries over.

Taylor rule with flexible-price output gap In keeping with Blanchard and Riggi (2013), our baseline model features a monetary policy rule that reacts to the welfare-relevant output gap, defined as the deviation of actual output from its efficient level (i.e. the counterfactual level of output under perfect competition in goods and labor markets). Blanchard and Riggi (2013) point out that, in a model with real wage rigidity and oil price shocks, the flexible-price output gap (i.e. the deviation

[32] Strictly speaking, the feedback rule specified by Justiniano et al. (2013) features a time-varying inflation target and does not include an output gap measure. Introducing a time-varying inflation target would reinforce our determinacy result (Haque, 2019). Removing the output gap from the policy rule would also increase the likelihood of determinacy.

of actual output from the natural level prevailing in absence of nominal rigidities) is much more volatile than the welfare-relevant output gap. To demonstrate robustness, we also estimate a version of our model where the Taylor rule responds to the flexible-price output gap (Smets and Wouters 2007). The estimated response to the output gap for the pre-Volcker period turns out to be slightly higher. Yet, the findings that the Great Inflation era is characterized by determinacy and an active response of the central bank to inflation remain unchanged.

Indexation In line with Cogley and Sbordone's (2008) reported lack of intrinsic inertia in the GNK Phillips Curve, our baseline model does not feature any kind of indexation in price-setting. However, by containing the magnitude of price dispersion, inflation indexation offsets the effect of positive trend inflation on the determinacy region (Ascari and Sbordone 2014; Hirose et al. 2019).[33] It is therefore interesting to explore the sensitivity of our determinacy result with respect to the presence of indexation. Following Ascari et al. (2011), we introduce rule-of-thumb firms and estimate the degree of indexation to past inflation (see also Benati 2009). While finding some support for a moderate degree of indexation, the pre-Volcker period is still best characterized by determinacy.

6.2 Twists to the econometric strategy

We conclude this section by exploring the sensitivity of our findings to modifications in the econometric strategy. We conduct the following checks: (i) using oil price data as an observable (Nakov and Pescatori, 2010); (ii) calibrating the $\widetilde{M}$ parameters at the continuity solution (Lubik and Schorfheide, 2004); (iii) employing a different numerical approach to find the boundary between the determinacy and indeterminacy region.

Oil as an observable We now investigate the sensitivity of our results to directly using real oil price data as an observable. Until now, to identify commodity price disturbances, we have treated simultaneously headline and core inflation as observ-

[33] In our model, if all prices are adjusted every period, some optimally, the rest mechanically through indexation to past inflation, the usual Taylor principle is restored.

Table 8: Determinacy versus Indeterminacy (Robustness)

	1966:I-1979:II		1984:I-2008:II	
	Log-density	Prob. of det.	Log-density	Prob. of det.
Baseline	-279.3	1	-275.7	1
TR no Core ($\tau = 1$)	-281.4	1	-310.1	1
TR w. annual rates	-287.1	0.9	-290.1	1
TR w. flex-price output gap	-276.7	0.9	-280.4	1
Indexation	-278.4	1	-286.6	1
Oil price as observable	-504.8	0.8	-625.1	1
Prior 2 of LS (2004)	-280.3	1	-274.2	1
Boundary: Perturb. (ψ_π, ψ_x)	-280.6	0.8	-277.7	1

ables. This approach identifies cost-push shocks broadly as commodity price shocks (including food prices as well as other commodity prices). For instance, the two inflationary episodes in the 1970s also featured sizeable food-price hikes as documented by Blinder and Rudd (2012). As food receives a larger weight than energy in the headline consumer price index, ignoring food prices may be problematic. Nonetheless, we check the robustness of our results to directly using real oil prices as an observable to identify the episodes of oil price shocks in isolation (Nakov and Pescatori 2010). We use the West Texas Intermediate oil price and deflate it with the core consumer price index to align the empirical measure with the concept of real oil price in the model. We then compute percentage changes and demean the resulting series by its sub-sample mean prior to the estimation. Compared to our baseline set of observables, we replace headline CPI inflation with the quarterly rate of growth in real oil prices. Again, our results remain robust.

Alternative formulation of indeterminacy Recall that indeterminacy alters the propagation of fundamental shocks as discussed in Section 3. The dynamics of fundamental shocks are not uniquely pinned down under indeterminacy and this mutiplicity is captured by the vector $\widetilde{M}$. Following Lubik and Schorfheide's (2004) 'Prior 1', we set $\widetilde{M} = M^* (\theta) + M$ in the analysis so far, where $M^* (\theta)$ is calibrated by making the impact response of endogenous variables to fundamental shocks continuous at the boundary between the (in)-determinacy region while M is estimated using a standard normal prior. We now consider what Lubik and Schorfheide (2004) call 'Prior 2', which is obtained by imposing $M = 0$ and restricting the likelihood function to the baseline indeterminacy solution $\widetilde{M} = M^* (\theta)$ (i.e. the continuity solution in Lubik and Schorfheide's terminology). Our results remain very much unchanged.

Hitting the boundary Lubik and Schorfheide (2004) center the priors of the indeterminacy parameters at the continuity solution. In our GNK model, the higher-order dynamics makes an analytical derivation of the determinacy conditions infeasible and we must therefore resort to numerical methods to trace the boundary. Following Justiniano and Primiceri (2008) and Hirose (2014), so far we have perturbed ψ_π until reaching a value that satisfies the Blanchard-Kahn condition. We now explore the robustness of our results to perturbing ψ_π and ψ_x simultaneously. Under positive trend inflation, the boundary involves many parameters. In particular, as we have discussed above, the central bank's response to the output gap ψ_x plays a critical role in the determinacy conditions (see Figure 3). As such, the indeterminacy test may be susceptible to the precise location on the boundary at which the priors of the indeterminacy parameters are centered. To check this, we center these priors at a different point on the boundary (i.e. a different continuity solution). Instead of travelling towards the boundary by only perturbing ψ_π, we incrementally increase ψ_π while simultaneously reducing ψ_x until we hit the boundary. The data still favors determinacy and an active response to inflation during the Great Inflation.

7 Conclusion

To what extent did monetary policy contribute to the Great Inflation? This question has engaged many researchers since the seminal contribution of Clarida et al. (2000) who estimated interest-rate rules in isolation and found a passive response to inflation for the pre-Volcker period, suggesting that U.S. monetary policy before 1979 was consistent with equilibrium indeterminacy. Lubik and Schorfheide (2004) reached the same view while treating indeterminacy as a property of a system (i.e. the New Keynesian model): loose monetary policy led to mercurial inflation. A similar conclusion appears in models with trend inflation. Coibion and Gorodnichenko (2011) using single-equation estimations and Hirose et al. (2017) employing general equilibrium estimations both suggest that the Great Inflation can be best understood as the result of equilibrium indeterminacy.

The current paper advances an alternative hypothesis in an estimated GNK economy which simultaneously considers trend inflation, real wage sluggishness and cost-push shocks. In such an environment, sticky wages and inefficient supply shocks generate a strong negative correlation between inflation and the output gap, thereby confronting the monetary authority with a difficult trade-off. This trade-off inherently influences the parameter estimates of the central bank's interest rate rule. Given the latent nature of the model-consistent output gap, it is crucial to adopt a system-based approach to estimation. Our econometric strategy critically disciplines the identification of cost-push shocks and provides evidence for sluggish real wages during the Seventies. Our analysis makes the case that the Federal Reserve's conduct of monetary policy before 1979 was inconsistent with equilibrium indeterminacy. In particular, we find that the Federal Reserve responded aggressively to inflation while its response to the output gap was almost negligible. Phrased alternatively, we do not find empirical evidence for indeterminacy in the U.S. economy.

Do our findings then imply that monetary policy had no destabilizing effect even in the Seventies? No. In fact, we show that had the Federal Reserve followed the policy rule of the post-1984 period already during the Seventies, inflation volatility would have been reduced by roughly a third. Nevertheless, the evolution of monetary policy across the two periods cannot explain the drop in output growth volatility which appears to be primarily the result of a decline in wage rigidity combined with smaller aggregate demand shocks. We further document that oil price shocks have become less stagflationary during the Great Moderation period, as a result of the decline in real wage rigidity.

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A Appendix (Supplementary material)

In this Appendix to "Do We Really Know that U.S. Monetary Policy was Destabilizing in the 1970s?", we provide the readers with a more detailed description of the data and the model. We also report some of our estimation tables that we discuss (briefly) in the main paper but have decided to put into the Appendix to conserve space. We will begin by reporting the data and then set up the complete model. The Appendix closes by reporting Tables A1 and A2.

A.1 Data sources

This part of the Appendix details the sources of the data used in the estimation. All data is quarterly and for the period 1966:I-2008:II.

1. Real Gross Domestic Product: U.S. Bureau of Economic Analysis, Real Gross Domestic Product [GDPC1], retrieved from FRED, Federal Reserve Bank of St. Louis

https://fred.stlouisfed.org/series/GDPC1.

2. CPI: U.S. Bureau of Labor Statistics, Consumer Price Index for All Urban Consumers: All Items [CPIAUCSL], retrieved from FRED, Federal Reserve Bank of St. Louis

https://fred.stlouisfed.org/series/CPIAUCSL.

3. Core CPI: U.S. Bureau of Labor Statistics, Consumer Price Index for All Urban Consumers: All Items Less Food and Energy [CPILFESL], retrieved from FRED, Federal Reserve Bank of St. Louis

https://fred.stlouisfed.org/series/ CPILFESL.

4. Wage series 1: U.S. Bureau of Labor Statistics, Nonfarm Business Sector: Compensation Per Hour [PRS85006101], retrieved from FRED, Federal Reserve Bank of St. Louis

https://fred.stlouisfed.org/series/PRS85006101.

5. Wage series 2: U.S. Bureau of Labor Statistics, Average Hourly Earnings of Production and Nonsupervisory Employees: Total Private [AHETPI], retrieved from FRED, Federal Reserve Bank of St. Louis

https://fred.stlouisfed.org/series/AHETPI.

6. Federal Funds Rate: Board of Governors of the Federal Reserve System (US), Effective Federal Funds Rate [FEDFUNDS], retrieved from FRED, Federal Reserve Bank of St. Louis

https://fred.stlouisfed.org/series/FEDFUNDS.

7. Oil price: Dow Jones & Company, Spot Oil Price: West Texas Intermediate (DISCONTINUED) [OILPRICE], retrieved from FRED, Federal Reserve Bank of St. Louis

https://fred.stlouisfed.org/series/OILPRICE.

A.2 Model

The artificial economy is a Generalized New Keynesian economy with a commodity product which we interpret as oil. The economy consists of monopolistically competitive wholesale firms that produce differentiated goods using labor and oil. These goods are bought by perfectly competitive firms who weld them together into the final good that can be consumed. People rent out their labor services on competitive markets. Firms and households are price takers on the market for oil. The economy boils down to a variant of the model in Blanchard and Gali (2010) when approximated around a zero inflation steady state.

A.2.1 Households

The representative agent's preferences depend on consumption, C_t, and hours worked, N_t, and they are represented by the expected utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t d_t u(C_t, N_t) \qquad 0 < \beta < 1$$

which the agent acts to maximize. Here, E_t represents the expectations operator. The term d_t stands for a shock to the discount factor β which follows the stationary autoregressive process

$$\ln d_t = \rho_d \ln d_{t-1} + \epsilon_{d,t}$$

where $\epsilon_{d,t}$ is a zero-mean, serially uncorrelated innovation that is normally distributed with standard deviation σ_d. The period utility is additively separable in consumption and hours worked and it takes on the functional form

$$u(C_t, N_t) = \ln\left(C_t - h\widetilde{C}_{t-1}\right) - \nu_t \frac{N_t^{1+\varphi}}{1+\varphi} \qquad \varphi \geq 0.$$

Logarithmic utility is the only additive-separable form consistent with balanced growth. The term φ is the inverse of the Frisch labor supply elasticity, $h \in [0,1)$ stands for the degree of external habit persistence in consumption, and ν_t denotes a shock to the disutility of labor which follows

$$\ln \nu_t = \rho_\nu \ln \nu_{t-1} + \epsilon_{\nu,t}$$

where $\epsilon_{\nu,t}$ is $N(0, \sigma_\nu^2)$. The overall consumption basket, C_t, is a Cobb-Douglas bundle of output of domestically produced goods , $C_{q,t}$, and imported oil, $C_{m,t}$. In particular, we assume

$$C_t = \Theta_\chi C_{m,t}^{\chi} C_{q,t}^{1-\chi} \qquad 0 \leq \chi < 1$$

where $\Theta_\chi \equiv \chi^{-\chi}(1-\chi)^{-(1-\chi)}$. The parameter χ equals the share of energy in total consumption. The agent sells labor services to the wholesale firms at the nominal wage W_t and has access to a market for one-period riskless bonds, B_t, at the interest rate R_t. Any generated profits, Π_t, flow back and the period budget is constrained by

$$W_t N_t + B_{t-1} + \Pi_t \geq P_{q,t} C_{q,t} + P_{m,t} C_{m,t} + \frac{B_t}{R_t}$$

where $P_{q,t}$ denotes the domestic output price index. The Euler equation is given by

$$\frac{d_t}{P_{c,t}\left(C_t - hC_{t-1}\right)} = \beta E_t \frac{R_t d_{t+1}}{P_{c,t+1}\left(C_{t+1} - hC_t\right)}$$

where $P_{c,t}$ is the price of the overall consumption basket. The intra-temporal optimality condition is described by

$$\frac{W_t}{P_{c,t}} = \nu_t N_t^{\varphi}\left(C_t - hC_{t-1}\right) \equiv MRS_t.$$

Following Blanchard and Gali (2007, 2010) and Blanchard and Riggi (2013), we formalize real wage rigidities by modifying the previous equation as

$$\frac{W_t}{P_{c,t}} = \left\{\frac{W_{t-1}}{P_{c,t-1}}\right\}^{\gamma} \{MRS_t\}^{1-\gamma}$$

where γ is the degree of real wage rigidity. In the optimal allocation, we have

$$P_{q,t}C_{q,t} = (1-\chi)P_{c,t}C_t$$

and

$$P_{m,t}C_{m,t} = \chi P_{c,t}C_t$$

where $P_{c,t} \equiv P_{m,t}^{\chi}P_{q,t}^{1-\chi}$ and $P_{m,t}$ is the nominal price of oil. Also note $P_{c,t} \equiv P_{q,t}s_t^{\chi}$, where $s_t \equiv \frac{P_{m,t}}{P_{q,t}}$ is the real price of oil that follows an exogenous process given by

$$\ln s_t = \rho_s \ln s_{t-1} + \epsilon_{s,t}.$$

A.2.2 Firms

The representative final good firm produces a homogenous good Q_t by choosing a combination of intermediate inputs $Q_t(i)$ to maximize profit. Specifically, the problem of the final good firm is to solve:

$$\max_{Q_t(i)} P_{q,t}Q_t - \int_0^1 P_{q,t}(i)Q_t(i)di$$

subject to the CES production technology

$$Q_t = \left[\int_0^1 Q_t(i)^{\frac{\varepsilon-1}{\varepsilon}}di\right]^{\frac{\varepsilon}{\varepsilon-1}}$$

where $P_{q,t}(i)$ is the price of the intermediate good i and ε is the elasticity of substitution between intermediate goods. Then the final good firm's demand for intermediate good i is given by

$$Q_t(i) = \left(\frac{P_{q,t}(i)}{P_{q,t}}\right)^{-\varepsilon} Q_t.$$

Substituting this demand for retail good i into the CES bundler function gives

$$P_{q,t} = \left[\int_0^1 P_{q,t}(i)^{1-\varepsilon}di\right]^{\frac{1}{1-\varepsilon}}.$$

Intermediate goods are produced using labor, $N_t(i)$, and oil, $M_t(i)$, both supplied on perfectly competitive factor markets. Each firm i produces according to the production function

$$Q_t(i) = [A_tN_t(i)]^{1-\alpha}M_t(i)^{\alpha} \qquad 0 \le \alpha < 1$$

where α is the share of oil in production and A_t denotes non-stationary labor-augmenting technology

$$\ln A_t = \ln \overline{g} + \ln A_{t-1} + \epsilon_{z,t}.$$

Here, $\overline{g}$ is the steady-state gross rate of technological change and $\epsilon_{z,t}$ is $N(0, \sigma_z^2)$. Each intermediate good-producing firm's marginal cost is given by

$$\psi_t(i) = \frac{W_t}{(1-\alpha)Q_t(i)/N_t(i)} = \frac{P_{m,t}}{\alpha Q_t(i)/M_t(i)}$$

and the markup, $\mathcal{M}_t^P(i)$, equals

$$\mathcal{M}_t^P(i) = \frac{P_{q,t}(i)}{\psi_t(i)}.$$

Given the production function, cost minimization implies that the firms' demand for oil is given by:

$$M_t(i) = \frac{\alpha}{\mathcal{M}_t^P(i)} \frac{Q_t(i)}{s_t} \frac{P_{q,t}(i)}{P_{q,t}}.$$

Letting Q_t also denote aggregate gross output and defining $\Delta_t \equiv \int_0^1 (\frac{P_{q,t}(i)}{P_{q,t}})^{-\varepsilon} di$ as the relative price dispersion measure, it follows that

$$M_t = \frac{\alpha}{\mathcal{M}_t^P} \frac{Q_t}{s_t} \Delta_t^{\frac{\varepsilon-1}{\varepsilon}}$$

where we have used the demand schedule faced by intermediate good firm i and defined the average gross markup as $\mathcal{M}_t^P \equiv \int_0^1 \mathcal{M}_t^P(i) di$. Next, combining the cost minimization conditions for oil and for labor with the aggregate production function yields the following factor price frontier:

$$\left(\frac{W_t}{P_{c,t}}\right)^{1-\alpha} \mathcal{M}_t^P = \mathcal{C} A_t^{1-\alpha} s_t^{-\alpha-\chi(1-\alpha)} \Delta_t^{-\frac{1}{\varepsilon}}$$

where $\mathcal{C} \equiv \left[\frac{1}{(1-\chi)\Theta_\chi} \left(\frac{1-\chi}{\chi}\right)^\chi\right]^{\alpha-1} \alpha^\alpha (1-\alpha)^{1-\alpha}$. The intermediate goods producers face a constant probability, $0 < 1-\xi < 1$, of being able to adjust prices to a new optimal one, $P_{q,t}^*(i)$, in order to maximize expected discounted profits

$$E_t \sum_{j=0}^{\infty} \xi^j \beta^j \frac{\lambda_{t+j}}{\lambda_0} \left[\frac{P_{q,t}^*(i)}{P_{q,t+j}} Q_{t+j}(i) - \frac{W_{t+j}}{(1-\alpha)P_{q,t+j} A_{t+j}^{1-\alpha}} \left\{\frac{(1-\alpha)P_{m,t+j}}{\alpha W_{t+j}}\right\}^\alpha Q_{t+j}(i)\right]$$

subject to the constraint

$$Q_{t+j}(i) = \left[\frac{P_{q,t}^*(i)}{P_{q,t+j}}\right]^{-\varepsilon} Q_{t+j}$$

where

$$\lambda_{t+j} = \frac{d_{t+j}}{P_{c,t+j}\left(C_{t+j} - hC_{t+j-1}\right)}.$$

The first order condition for the optimized relative price $p^*_{q,t}(i) \equiv \frac{P^*_{q,t}(i)}{P_{q,t}}$ is given by

$$p^*_{q,t}(i) = \frac{\varepsilon}{(\varepsilon-1)(1-\alpha)} \frac{E_t \sum_{j=0}^{\infty} (\xi\beta)^j \lambda_{t+j} \frac{W_{t+j}}{P_{q,t+j} A_{t+j}^{1-\alpha}} \left[\frac{(1-\alpha)P_{m,t+j}}{\alpha W_{t+j}}\right]^{\alpha} \left[\frac{P_{q,t}}{P_{q,t+j}}\right]^{-\varepsilon} Q_{t+j}}{E_t \sum_{j=0}^{\infty} (\xi\beta)^j \lambda_{t+j} \left[\frac{P_{q,t}}{P_{q,t+j}}\right]^{1-\varepsilon} Q_{t+j}}.$$

The joint dynamics of the optimal reset price and inflation can be compactly described by rewriting the first-order condition for the optimal price in a recursive formulation as follows:

$$p^*_{q,t}(i) = \frac{\varepsilon}{(\varepsilon-1)(1-\alpha)} \frac{\kappa_t}{\phi_t}$$

where κ_t and ϕ_t are auxiliary variables that allow one to rewrite the infinite sums that appear in the numerator and denominator of the above equation in recursive formulation:

$$\kappa_t = \mathcal{C}\left(\frac{W_t}{P_{c,t}}\right)^{1-\alpha} s_t^{\chi(1-\alpha)+\alpha} A_t^{\alpha-1} Q_t \widetilde{\lambda}_t + \xi\beta\left[E_t \pi^{\varepsilon}_{q,t+1} \kappa_{t+1}\right]$$

and

$$\phi_t = Q_t \widetilde{\lambda}_t + \xi\beta\left[E_t \pi^{\varepsilon-1}_{q,t+1} \phi_{t+1}\right],$$

where we have used the definition $\widetilde{\lambda}_t = \lambda_t P_{c,t}$. Note that κ_t and ϕ_t can be interpreted as the present discounted value of marginal costs and marginal revenues respectively. Moreover, the aggregate price level evolves according to:

$$\begin{aligned}
P_{q,t} &= \left[\int_0^1 P_{q,t}(i)^{1-\varepsilon} di\right]^{\frac{1}{1-\varepsilon}} \Rightarrow \\
1 &= \xi \pi^{\varepsilon-1}_{q,t} + (1-\xi) p^*_{q,t}(i)^{1-\varepsilon} \\
p^*_{q,t}(i) &= \left[\frac{1-\xi\pi^{\varepsilon-1}_{q,t}}{1-\xi}\right]^{\frac{1}{1-\varepsilon}}.
\end{aligned}$$

A.2.3 Definitions

Production function is characterized by the following:

$$Q_t \Delta_t = M_t^{\alpha} (A_t N_t)^{1-\alpha}.$$

The condition that trade be balanced gives us a relation between consumption and gross output:

$$P_{c,t}C_t = \left(1 - \frac{\alpha}{\mathcal{M}_t^P}\Delta_t^{\frac{\varepsilon-1}{\varepsilon}}\right) P_{q,t}Q_t.$$

The GDP deflator $P_{y,t}$ is implicitly defined by

$$P_{q,t} \equiv (P_{y,t})^{1-\alpha} (P_{m,t})^{\alpha}.$$

Value added (or GDP) is then defined by

$$P_{y,t}Y_t = \left(1 - \frac{\alpha}{\mathcal{M}_t^P}\Delta_t^{\frac{\varepsilon-1}{\varepsilon}}\right) P_{q,t}Q_t.$$

Recall that price dispersion is defined as $\Delta_t \equiv \int_0^1 (\frac{P_{q,t}(i)}{P_{q,t}})^{-\varepsilon} di$. Under the Calvo price mechanism, the above expression can be written recursively as:

$$\Delta_t = (1-\xi)p_{q,t}^*(i)^{-\varepsilon} + \xi\pi_{q,t}^{\varepsilon}\Delta_{t-1}.$$

A.2.4 Monetary policy

Lastly, the model is closed by assuming that short-term nominal interest rate follows a feedback rule, of the type that has been found to provide a good description of actual monetary policy in the U.S. since Taylor (1993). Our specification of this policy rule features interest rate smoothing, a systematic response to deviations of inflation, output gap and output growth from their respective target values.

$$R_t = \widetilde{R}_t^{1-\rho_R} R_{t-1}^{\rho_R} \exp\{\varepsilon_{R,t}\}, \qquad \widetilde{R}_t = \overline{R}^{-1} \left\{ \left(\frac{\pi_{c,t}}{\overline{\pi}}\right)^{\tau} \left(\frac{\pi_{q,t}}{\overline{\pi}}\right)^{1-\tau} \right\}^{\psi_\pi} \left\{\frac{Y_t}{Y_t^*}\right\}^{\psi_x} \left\{\frac{Y_t/Y_{t-1}}{\overline{g}}\right\}^{\psi_g}$$

where $\overline{\pi}$ denotes the central bank's inflation target (and is equal to the gross level of trend inflation), $\overline{R}$ is the gross steady-state policy rate, $\overline{g}$ is the gross steady state growth rate of the economy and $\varepsilon_{R,t}$ is an i.i.d. monetary policy shock. The output gap measures the deviation of the actual level of GDP Y_t from the efficient level of GDP, Y_t^*, i.e. the counterfactual level of GDP that would arise in the absence of monopolistic competition, nominal price stickiness and real wage rigidity. The central bank responds to a convex combination of headline and core inflation (with the parameter τ governing the relative weights; setting τ to one implies that the central bank responds to headline inflation only). The coefficients ψ_π, ψ_x and ψ_g govern the central bank's responses to inflation, output gap and output growth from their respective target values, and $\rho_R \in [0, 1]$ is the degree of policy rate smoothing .

Tables A1 and A2 report the posterior means and 90 percent highest posterior density intervals of the parameters for the robustness checks.

Table A1: Parameter Estimates, Robustness (1966:I-1979:II)

	JPT rule	Boundary	Output gap	Indexation	Oil price data	$\tau = 1$	LS Prior 2
ψ_π	1.31 [1.06,1.62]	1.34 [0.68,1.77]	1.44 [1.19,1.67]	1.38 [1.14,1.61]	1.37 [0.79,1.72]	1.48 [1.22,1.76]	1.51 [1.25,1.79]
ψ_x	0.08 [0.00,0.18]	0.04 [0.00,0.09]	0.13 [0.00,0.28]	0.05 [0.00,0.11]	0.05 [0.00,0.17]	0.03 [0.00,0.07]	0.03 [0.00,0.08]
ψ_g	0.50 [0.14,0.73]	0.30 [0.07,0.54]	0.40 [0.17,0.64]	0.31 [0.09,0.51]	0.43 [0.09,0.67]	0.36 [0.11,0.57]	0.34 [0.11,0.55]
ρ_R	0.64 [0.53,0.75]	0.66 [0.56,0.77]	0.69 [0.60,0.77]	0.68 [0.58,0.77]	0.69 [0.60,0.77]	0.70 [0.62,0.79]	0.68 [0.59,0.77]
τ	0.77 [0.55,0.96]	0.55 [0.32,0.81]	0.47 [0.18,0.75]	0.58 [0.34,0.84]	0.38 [0.13,0.63]	1	0.58 [0.31,0.82]
π^*	1.37 [1.00,1.66]	1.34 [1.06,1.64]	1.38 [1.11,1.65]	1.37 [1.06,1.69]	1.47 [1.10,1.76]	1.36 [1.08,1.64]	1.37 [1.08,1.62]
R^*	1.57 [1.21,1.87]	1.50 [1.17,1.81]	1.53 [1.20,1.85]	1.53 [1.20,1.88]	1.65 [1.29,1.95]	1.49 [1.17,1.83]	1.53 [1.19,1.84]
g^*	0.47 [0.35,0.60]	0.46 [0.34,0.57]	0.44 [0.33,0.56]	0.45 [0.33,0.56]	0.43 [0.30,0.57]	0.45 [0.34,0.58]	0.45 [0.34,0.57]
ξ	0.62 [0.54,0.66]	0.59 [0.52,0.65]	0.60 [0.54,0.66]	0.59 [0.53,0.66]	0.64 [0.57,0.69]	0.60 [0.53,0.66]	0.60 [0.53,0.66]
γ	0.91 [0.87,0.95]	0.89 [0.83,0.95]	0.87 [0.82,0.94]	0.90 [0.85,0.95]	0.91 [0.86,0.96]	0.89 [0.83,0.94]	0.89 [0.83,0.94]
h	0.43 [0.32,0.55]	0.38 [0.27,0.48]	0.37 [0.27,0.48]	0.40 [0.28,0.51]	0.30 [0.20,0.41]	0.38 [0.27,0.50]	0.37 [0.26,0.49]
ω	–	–	–	0.44 [0.31,0.59]	–	–	–
ρ_d	0.68 [0.56,0.82]	0.74 [0.65,0.86]	0.76 [0.65,0.87]	0.76 [0.65,0.87]	0.81 [0.64,0.92]	0.77 [0.65,0.87]	0.77 [0.66,0.86]
ρ_ν	0.78 [0.64,0.90]	0.85 [0.74,0.96]	0.89 [0.81,0.97]	0.85 [0.75,0.94]	0.75 [0.52,0.93]	0.86 [0.74,0.97]	0.86 [0.74,0.96]
σ_s	17.33 [14.4,20.1]	17.04 [14.6,19.5]	17.25 [14.5,19.7]	17.22 [14.5,19.6]	17.21 [14.6,19.9]	17.11 [14.3,19.6]	17.39 [14.6,20.1]
σ_g	0.51 [0.35,0.67]	0.50 [0.35,0.63]	0.49 [0.35,0.62]	0.45 [0.33,0.58]	0.56 [0.41,0.71]	0.48 [0.34,0.62]	0.48 [0.34,0.63]
σ_r	0.27 [0.22,0.34]	0.31 [0.25,0.36]	0.30 [0.25,0.36]	0.29 [0.24,0.35]	0.32 [0.25,0.40]	0.30 [0.24,0.35]	0.30 [0.25,0.36]
σ_d	2.10 [1.52,2.63]	1.60 [0.80,2.22]	1.68 [1.22,2.21]	1.97 [1.40,2.54]	2.07 [1.38,2.64]	1.87 [1.32,2.42]	1.83 [1.31,2.35]
σ_ν	0.34 [0.24,0.48]	0.41 [0.27,0.57]	0.40 [0.27,0.53]	0.42 [0.29,0.55]	0.36 [0.19,0.51]	0.37 [0.26,0.50]	0.37 [0.26,0.50]
σ_ζ	0.49 [0.20,0.78]	0.44 [0.23,0.64]	0.46 [0.20,0.71]	0.45 [0.21,0.71]	0.43 [0.20,0.66]	0.45 [0.21,0.70]	0.45 [0.21,0.70]
$M_{s,\zeta}$	0.05 [−1.63,1.59]	0.16 [−1.29,1.32]	−0.08 [−1.60,1.51]	0.07 [−1.49,1.69]	0.28 [−1.33,1.64]	−0.07 [−1.70,1.52]	0
$M_{g,\zeta}$	−0.07 [−1.75,1.60]	0.08 [−1.50,1.51]	0.01 [−1.65,1.63]	0.00 [−1.60,1.62]	0.10 [−1.57,1.64]	0.05 [−1.59,1.71]	0
$M_{r,\zeta}$	0.06 [−1.56,1.69]	−0.02 [−1.45,1.51]	−0.01 [−1.61,1.53]	0.00 [−1.67,1.52]	−0.29 [−1.71,1.48]	0.05 [−1.61,1.62]	0
$M_{d,\zeta}$	0.00 [−1.67,1.61]	0.12 [−1.47,1.63]	0.16 [−1.62,1.82]	0.07 [−1.60,1.71]	0.19 [−1.55,1.71]	0.14 [−1.54,1.79]	0
$M_{\nu,\zeta}$	−0.15 [−1.77,1.60]	0.02 [−1.44,1.65]	−0.06 [−1.72,1.54]	0.01 [−1.59,1.74]	0.04 [−1.40,1.63]	0.01 [−1.65,1.62]	0
λ	1.00 [0.59,1.40]	1.09 [0.70,1.50]	1.08 [0.71,1.44]	1.09 [0.73,1.43]	0.97 [0.52,1.49]	1.08 [0.68,1.47]	1.06 [0.66,1.45]
σ_{w_1}	0.34 [0.14,0.49]	0.36 [0.20,0.50]	0.38 [0.21,0.53]	0.39 [0.25,0.54]	0.31 [0.13,0.49]	0.38 [0.20,0.52]	0.37 [0.19,0.52]
σ_{w_2}	0.51 [0.36,0.66]	0.42 [0.21,0.59]	0.43 [0.28,0.61]	0.44 [0.30,0.61]	0.51 [0.34,0.67]	0.45 [0.29,0.63]	0.46 [0.31,0.63]

Table A2: Parameter Estimates, Robustness (1984:I-2008:II)

	JPT rule	Boundary	Output gap	Indexation	Oil price data	$\tau = 1$	LS Prior 2
ψ_π	2.92 [2.37,3.36]	2.95 [2.45,3.45]	2.16 [1.78,2.51]	3.06 [2.47,3.56]	2.86 [2.27,3.45]	2.16 [1.66,2.68]	3.03 [2.42,3.56]
ψ_x	0.29 [0.04,0.47]	0.11 [0.03,0.18]	0.13 [0.00,0.27]	0.17 [0.05,0.30]	0.07 [0.02,0.13]	0.08 [0.00,0.28]	0.10 [0.03,0.17]
ψ_g	0.58 [0.24,0.78]	0.61 [0.40,0.83]	0.58 [0.28,0.75]	0.51 [0.29,0.70]	0.60 [0.32,0.77]	0.62 [0.27,0.91]	0.69 [0.44,0.90]
ρ_R	0.62 [0.51,0.71]	0.71 [0.65,0.78]	0.72 [0.64,0.78]	0.70 [0.62,0.77]	0.74 [0.66,0.79]	0.81 [0.76,0.86]	0.73 [0.67,0.79]
τ	0.19 [0.07,0.34]	0.13 [0.04,0.22]	0.20 [0.07,0.31]	0.12 [0.04,0.21]	0.16 [0.06,0.29]	1	0.14 [0.05,0.22]
π^*	0.96 [0.80,1.12]	0.94 [0.79,1.07]	0.94 [0.82,1.06]	0.94 [0.79,1.08]	0.96 [0.79,1.10]	1.04 [0.85,1.20]	0.98 [0.83,1.13]
R^*	1.48 [1.23,1.74]	1.43 [1.20,1.65]	1.44 [1.23,1.67]	1.47 [1.25,1.71]	1.46 [1.22,1.70]	1.53 [1.29,1.77]	1.47 [1.24,1.69]
g^*	0.22 [0.15,0.33]	0.18 [0.10,0.25]	0.14 [0.08,0.24]	0.18 [0.10,0.26]	0.15 [0.08,0.25]	0.19 [0.12,0.26]	0.16 [0.08,0.24]
ξ	0.68 [0.60,0.72]	0.61 [0.53,0.68]	0.67 [0.59,0.73]	0.51 [0.43,0.59]	0.64 [0.57,0.69]	0.70 [0.63,0.75]	0.63 [0.56,0.69]
γ	0.65 [0.52,0.77]	0.44 [0.25,0.64]	0.57 [0.38,0.74]	0.30 [0.13,0.48]	0.60 [0.43,0.75]	0.59 [0.33,0.79]	0.49 [0.31,0.68]
h	0.30 [0.21,0.39]	0.24 [0.16,0.33]	0.30 [0.21,0.41]	0.21 [0.14,0.30]	0.31 [0.22,0.41]	0.30 [0.19,0.44]	0.26 [0.17,0.34]
ω	–	–	–	0.30 [0.17,0.44]	–	–	–
ρ_d	0.82 [0.75,0.88]	0.85 [0.79,0.91]	0.85 [0.77,0.91]	0.84 [0.77,0.89]	0.83 [0.76,0.89]	0.85 [0.79,0.91]	0.84 [0.78,0.89]
ρ_ν	0.94 [0.86,0.99]	0.99 [0.98,0.99]	0.98 [0.96,0.99]	0.99 [0.98,0.99]	0.98 [0.97,0.99]	0.91 [0.67,0.99]	0.98 [0.98,0.99]
σ_s	14.86 [13.1,16.6]	14.92 [13.2,16.6]	14.98 [13.2,16.8]	14.81 [13.2,16.5]	12.76 [11.3,14.3]	15.20 [13.5,16.7]	14.86 [13.2,16.4]
σ_g	0.56 [0.42,0.68]	0.43 [0.30,0.56]	0.53 [0.35,0.65]	0.43 [0.30,0.56]	0.45 [0.31,0.58]	0.62 [0.43,0.84]	0.46 [0.31,0.58]
σ_r	0.14 [0.12,0.16]	0.18 [0.15,0.20]	0.17 [0.15,0.20]	0.18 [0.15,0.22]	0.17 [0.14,0.20]	0.19 [0.16,0.22]	0.17 [0.15,0.20]
σ_d	1.57 [1.18,1.89]	1.21 [0.88,1.52]	1.18 [0.88,1.41]	1.12 [0.84,1.38]	1.21 [0.91,1.45]	1.30 [0.99,1.56]	1.18 [0.91,1.42]
σ_ν	0.44 [0.30,0.57]	0.78 [0.52,1.03]	0.70 [0.49,0.95]	0.92 [0.68,1.14]	0.62 [0.42,0.83]	0.53 [0.30,0.79]	0.72 [0.50,0.96]
σ_ζ	0.42 [0.21,0.63]	0.53 [0.21,0.89]	0.44 [0.21,0.71]	0.43 [0.21,0.64]	0.48 [0.21,0.72]	0.53 [0.21,0.85]	0.44 [0.20,0.67]
$M_{s,\zeta}$	−0.18 [−1.74,1.49]	0.08 [−1.46,1.77]	−0.05 [−1.59,1.65]	0.17 [−1.47,1.79]	−0.15 [−.175,1.48]	−0.33 [−0.99,1.58]	0
$M_{g,\zeta}$	−0.07 [−1.58,1.55]	0.01 [−1.55,1.57]	−0.06 [−1.66,1.53]	0.24 [−1.34,1.82]	−0.01 [−1.64,1.60]	−0.07 [−1.65,1.58]	0
$M_{r,\zeta}$	−0.17 [−1.71,1.48]	−0.11 [−1.68,1.41]	0.00 [−1.60,1.53]	−0.34 [−1.90,1.24]	−0.04 [−1.72,1.52]	0.22 [−1.38,1.72]	0
$M_{d,\zeta}$	0.07 [−1.57,1.71]	0.20 [−1.39,1.82]	0.04 [−1.57,1.59]	−0.03 [−1.49,1.53]	0.01 [−1.63,1.62]	0.96 [−0.79,2.51]	0
$M_{\nu,\zeta}$	0.13 [−1.55,1.65]	−0.04 [−1.65,1.41]	0.05 [−1.56,1.66]	−0.05 [−1.71,1.49]	−0.08 [−1.71,1.45]	−0.23 [−1.75,1.36]	0
λ	0.15 [0.00,0.27]	0.29 [0.16,0.42]	0.31 [0.18,0.45]	0.30 [0.17,0.42]	0.33 [0.15,0.49]	0.20 [0.05,0.36]	0.30 [0.16,0.42]
σ_{w_1}	0.73 [0.59,0.87]	0.66 [0.55,0.77]	0.59 [0.47,0.72]	0.67 [0.55,0.77]	0.63 [0.51,0.75]	0.65 [0.49,0.86]	0.64 [0.53,0.75]
σ_{w_2}	0.42 [0.36,0.50]	0.38 [0.32,0.44]	0.36 [0.31,0.43]	0.38 [0.32,0.44]	0.37 [0.31,0.44]	0.40 [0.34,0.47]	0.38 [0.32,0.44]