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Keywords

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JEL Classification

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In this paper we examine whether or not monetary policy was a source of instability during the Great Inflation. We focus on a number of attributes that we see relevant for any analysis of the 1970s: cost-push or oil price shocks, positive trend inflation as well as real wage rigidity. We turn our artificial sticky-price economy into a Bayesian model and find that the U.S. economy during the 1970s is best characterized by a high degree of real wage rigidity. Oil price shocks thus created a trade-off between inflation and output-gap stabilization. Faced with this dilemma, the Federal Reserve reacted aggressively to inflation but hardly at all to the output gap, thereby inducing stability, i.e. determinacy.

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1 Introduction

The Great Inflation episode was one of the defining macroeconomic events of the 20th century. From the late 1960s and throughout the 1970s, the U.S. economy went not only through levels of unemployment not seen since the 1930s but it also experienced high and volatile inflation. This episode is followed by a decline in macroeconomic volatility, a phenomenon coined the Great Moderation. Clarida, Galí and Gertler (2000) and Lubik and Schorfheide (2004) attribute the high inflation episode in the 1970s to expectations-driven fluctuations arising due to "passive" monetary policy. They argue that passive response to inflation in the pre-Volcker period induced aggregate instability, i.e. indeterminacy, with high levels and volatility of inflation. The transition to an "active" policy during the Volcker years stabilized inflation expectations, led to determinate outcome and removed sunspots as a source of economic instability. However, as pointed out by Bilbiie and Straub (2013), this indeterminacy-based explanation of the Great Inflation has one obvious problem: sunspot shocks are demand-driven in nature as they increase both inflation and output whereas the 1970s were plagued by stagflation.

The alternative hypothesis points to commodity price shocks as the important source of economic fluctuations. For instance, Hamilton (1983) argues that most U.S. recessions were Granger caused by increases in the price of crude oil. Bernanke, Gertler and Watson (1997) suggest that the Great Stagflation is linked to the endogenous response of the Federal Reserve to exogenous oil price shocks. According to their view, policy-makers raised interest rates in response to the oil price shock caused inflationary pressures, thereby causing a deep recession that would not have occurred otherwise. This interpretation is disputed by, amongst others, Barsky and Kilian (2002) who challenge the view that oil prices are exogenous and provide evidence that their rise in the 1970s was a response to macroeconomic forces, ultimately driven by shifts toward a less restrictive monetary policy regime after the breakdown of Bretton Woods. Such adverse cost-push shocks arguably generated a trade-off between stabilizing inflation and stabilizing the output gap for the Federal Reserve.

The empirical investigations that find passive response to inflation as well as endogenous instability in the 1970s have disregarded the effect of commodity price fluctuations and the associated policy trade-off. Indeed with no trade-off between stabilizing inflation and the output gap, full price stability becomes optimal. The fact that inflation was highly volatile in the 1970s suggests that either policy was far from optimal or indeed there was a policy trade-off.

In this paper, we revisit the *indeterminacy-based* explanation of the Great Inflation by adopting a framework which takes into account the trade-off faced by the central bank in the wake of adverse commodity price shocks. We extend a New Keynesian model with a role for oil in production and consumption and further allow for real wage rigidity as a mechanism generating quantitatively meaningful trade-offs for the central bank as in Blanchard and Galí (2007, 2010). What sets us apart is allowing for positive trend inflation - an important feature of the 1970s. In fact, Ascari and Ropele (2009) and others have shown that the dynamics of the New Keynesian model are dramatically altered when evaluated away from a zero-inflation steady state. Ascari and Sbordone (2014) show that trend inflation makes price-setting firms more forward-looking which effectively flattens the New Keynesian Phillips Curve and increases the parametric indeterminacy region. Uniqueness of equilibrium now requires even stronger policy responses to inflation. Hence, to reassess the evidence of indeterminacy in the 1970s in the face of commodity price shocks, one must also take into account the level of trend inflation.

We turn our sticky-price artificial economy into a Bayesian model and estimate over the Great Inflation and the Great Moderation periods. In addition to reassessing the evidence of loose monetary policy in the 1970s, this further allows us to study changes in monetary policy as well as changes in the propagation of commodity price shocks over time. Our results can be summarized as follows. First, we find that when considering the model without oil, indeterminacy prevails in the 1970s. This result is in line with the empirical monetary policy literature, for instance Lubik and Schorfheide (2004) and Hirose, Kurozumi and Van Zandweghe (2017). Second, once we introduce oil into the model, evidence for indeterminacy in the 1970s becomes weaker, i.e. we can no longer rule it in or out. However, important aspects of the analysis, such as oil price shocks and the degree of real wage rigidity, remain not properly identified. Third, adding observables (various price indices and wage data) sharpens the identification of these key features of the model, reveals that the Federal Reserve has been responding aggressively to inflation even in the 1970s to the extent that we can completely rule out indeterminacy. This discovery suggests that parameter estimates pertaining to the Taylor rule are biased when abstracting from modelling commodity price fluctuations and the associated trade-off. Fourth, our results indicate that there have been important changes in the U.S. economy in terms of both the policy parameters as well as the stochastic environment, i.e. the shock processes, between the two sub-samples. Most notably, the policy response to inflation and output growth almost doubled while trend inflation fell considerably. We also find that the Federal Reserve moved its focus away from responding to headline inflation during the pre-1979 period toward core inflation during the post-1984 period. Finally, we document that oil price shocks are no longer as inflationary as in the past, allowing the central bank to respond less aggressively to a given shock. This change to the propagation reflects more flexible wages in the second period as in Blanchard and Galí (2010) and Blanchard and Riggi (2013).

Our paper is closely related to the empirical literature studying the link between monetary policy and macroeconomic stability in the presence of trend inflation. Coibion and Gorodnichenko (2011) and Hirose, Kurozumi and Van Zandweghe (2017) find that the pre-Volcker period is characterized by indeterminacy while better systematic monetary policy as well as changes in the level of trend inflation resulted in a switch to determinacy in the early 1980s.[1] The current paper estimates a similar model while taking into account commodity price fluctuations and the trade-off faced by the central bank. Our interpretation that the pre-Volcker period should be characterized by determinacy is in line with Orphanides (2004), Bilbiie and Straub (2013) and Haque (2017). Both Orphanides (2004) and Haque (2017) document strong anti-inflationary stance pursued by the Federal Reserve even in the 1970s. While Orphanides (2004) points toward the mismeasurement of the output gap in real time, Haque (2017) suggests time variation in inflation target and its implications for the inflation gap as explanations for this finding. Bilbiie and Straub (2013) argue that limited asset market participation resulted in an inverted aggregate demand logic, i.e. interest rate increases become expansionary. Accordingly, they document passive monetary policy during the pre-Volcker period being consistent with equilibrium determinacy.

2 Model

The artificial economy is a Generalized New Keynesian (GNK) economy with a commodity product which we interpret as oil. This model offers a micro-founded setup that naturally features various inflation rates and also accounts for positive trend inflation. The economy consists of monopolistically competitive wholesale firms that

[1] Arias, Ascari, Branzoli and Castelnuovo (2017) do not estimate their model for the pre-1984 period and also do not allow for indeterminacy.

produce differentiated goods using labor and oil. These goods are bought by perfectly competitive firms (retailers) that 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.

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 that

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

where $\Theta_\chi \equiv \chi^{-\chi}(1-\chi)^{-(1-\chi)}$. The parameter χ equals the share of energy in total consumption and $C_{q,t}$ is an index of the domestic output described by

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

Here, the term ε measures the elasticity of demand for each intermediate good. 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

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

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

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

2.2 Firms

2.2.1 Final good firm

The representative final good firm produces 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 $\varepsilon > 1$ 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

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

2.2.2 Intermediate good firm

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

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

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

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

Here, $\overline{g}$ is the steady-state gross rate of technological change and z_t is a shock to the growth rate of technology following

$$\ln z_t = \rho_z \ln z_{t-1} + \epsilon_{z,t}$$

where $\epsilon_{z,t}$ 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 $\mathcal{C} \equiv \left[\frac{1}{(1-\chi)\Theta_\chi} \left(\frac{1-\chi}{\chi}\right)^\chi\right]^{\alpha-1} \alpha^\alpha (1-\alpha)^{1-\alpha}$.

Price setting 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:

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

Gross output Production function is characterized by the following:

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

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

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

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

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

GDP Value added (or GDP) is then defined by

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

Price dispersion 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:

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

2.3 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.

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

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, $\overline{x}$ is the steady state output gap, $\overline{g}$ 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 x_t measures the deviation of the actual level of GDP Y_t from the efficient level of GDP, 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, welfare-relevant output gap and output growth from their respective target values, and $\rho_R \in [0,1]$ is the degree of policy rate smoothing .

3 Solution under indeterminacy

To solve the rational expectations system, we follow the methodology of Lubik and Schorfheide (2003). This approach has the advantage of being general and explicit in dealing with expectation errors, thereby making the method suitable for solving models featuring multiple equilibria. Let us denote by η_t the vector of one-step ahead expectation errors. Moreover, define ϱ_t as the vector of endogenous variables and ε_t as vector of fundamental shocks. Then, the linear rational expectations system (LRE) can be compactly written as

$$\Gamma_0(\theta)\varrho_t = \Gamma_1(\theta)\varrho_{t-1} + \Psi(\theta)\varepsilon_t + \Pi(\theta)\eta_t, \tag{1}$$

where $\Gamma_0(\theta)$, $\Gamma_1(\theta)$, $\Psi(\theta)$ and $\Pi(\theta)$ are appropriately defined coefficient matrices. Under indeterminacy, η_t will be a linear function of the fundamental shocks and the purely extrinsic sunspot disturbances, ζ_t. Hence, the full set of solutions to the LRE model entails

$$\varrho_t = \Phi(\theta)\varrho_{t-1} + \Phi_\varepsilon(\theta, \widetilde{M})\varepsilon_t + \Phi_\zeta(\theta)\zeta_t, \tag{2}$$

where $\Phi(\theta)$, $\Phi_\varepsilon(\theta, \widetilde{M})$ and $\Phi_\zeta(\theta)^2$ are the coefficient matrices.[3] The sunspot shock satisfies $\zeta_t \sim i.i.d.\mathsf{N}(0, \sigma_\zeta^2)$. Indeterminacy alters the solution in two distinct ways. First and foremost, purely extrinsic non-fundamental disturbances, i.e. sunspots, affect model dynamics through endogenous formation of expectation errors. Second, the propagation of fundamental shocks are no longer uniquely pinned down and this multiplicity of equilibria affecting the propagation mechanism is captured by the arbitrary matrix $\widetilde{M}$.

Following Lubik and Schorfheide (2004), we replace $\widetilde{M}$ with $M^*(\theta) + M$ and in the subsequent empirical analysis set the prior mean for M equal to zero. This strategy selects $M^*(\theta)$ by using a least squares criterion to minimize the distance between the impact response of the endogenous variables to fundamental shocks, i.e. $\partial\varrho_t/\partial\varepsilon_t'$, at the boundary between the determinacy and the indeterminacy region. Analytical solution for the boundary in this model is infeasible. Hence we follow Justiniano and Primiceri (2008) and Hirose (2014) and resort to a numerical procedure to find the boundary by perturbing the parameter ψ_π in the monetary policy rule.[4] In a later

[2] Lubik and Schorfheide (2003) express this term as $\Phi_\zeta(\theta, M_\zeta)$, where M_ζ is an arbitrary matrix. For identification purpose, we impose their normalization such that $M_\zeta = I$.

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

[4] This methodology has been used in previous studies, such as Benati and Surico (2009), Doko Tchatoka, Groshenny, Haque and Weder (2017), Haque (2017), Hirose (2007, 2008, 2013, 2014) and Hirose, Kurozumi and Van Zandweghe (2017).

section, we also check the robustness of our results to an alternative perturbation for tracing the boundary.

4 Econometric Strategy

This section sets up the estimation procedure, lists the data and discusses the calibration and priors.

4.1 Bayesian estimation with Sequential Monte Carlo algorithm

We use Bayesian techniques for estimating the parameters of the model and test for indeterminacy using posterior model probabilities. In our estimation, we employ the Sequential Monte Carlo (SMC) algorithm proposed by Herbst and Schorfheide (2014, 2015) which is particularly suitable for irregular and non-elliptical posterior distributions. An added benefit of using an importance sampling algorithm like SMC is that the process does not require one to find the mode of the posterior distribution, a task that can prove to be difficult particularly under indeterminacy.

First the priors are described by a density function of the form

$$p(\theta_S|S).$$

Here $S \in \{D, I\}$ where D and I stand for determinacy and indeterminacy respectively, θ_S represents the parameter of the model S and $p(.)$ stands for probability density function. Next, the likelihood function

$$\mathcal{L}(\theta_S|X_T, S) \equiv p(X_T|\theta_S, S)$$

describes the density of the observed data and X_T denote observations through period T. By using Bayes theorem we can combine the prior density and the likelihood function to obtain the posterior density

$$p(\theta_S|X_T, S) = \frac{\mathcal{L}(\theta_S|X_T, S)p(\theta_S|S)}{p(X_T|S)}$$

in which $p(X_T|S)$ denotes the marginal density of the data conditional on the model which is given by

$$p(X_T|S) = \int_{\theta_S} \mathcal{L}(\theta_S|X_T, S)p(\theta_S|S)d\theta_S.$$

We employ the SMC algorithm of Herbst and Schorfheide (2014, 2015) to build a particle approximation of the posterior distribution through tempering the likelihood. A sequence of tempered posteriors is defined as

$$\pi_n(\theta_S) = \frac{[\mathcal{L}(\theta_S|X_T, S)]^{\phi_n} p(\theta_S|S)}{\int_{\theta_S}[\mathcal{L}(\theta_S|X_T, S)]^{\phi_n} p(\theta_S|S) d\theta_S}$$

where ϕ_n is the tempering schedule that slowly increases from zero to one and is determined by $\phi_n = \left(\frac{n-1}{N_\phi - 1}\right)^\delta$ 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 θ_n^i and N denotes the number of particles. The algorithm has three main steps. First, in the *correction* step, the particles are re-weighted to reflect the density in iteration n. Next, in the *selection* step, any particle degeneracy is eliminated by resampling the particles. A rule-of-thumb measure of this degeneracy, proposed by Herbst and Schorfheide (2014, 2015), is given by the reciprocal of the uncentered variance of the particles and is called the effective sample size (ESS) which is defined as:

$$\widehat{ESS_n} = \frac{N}{\frac{1}{N}\sum_{i=1}^N \left(\widetilde{W_i^n}\right)^2}$$

where $\widetilde{W_i^n}$ is the normalized particle weight. Following Herbst and Schorfheide (2014, 2015) we use systematic resampling whenever $\widehat{ESS_n} < \frac{N}{2}$. Finally, in the *mutation* step, the particles are propagated forward using a Markov transition kernel to adapt to the current bridge density. Here, we use one step of a single-block Random Walk Metropolis Hastings algorithm.

Note that in the first stage, i.e. when $n = 1$, ϕ_1 is zero. Hence, the prior density serves as an efficient proposal density for $\pi_1(\theta)$. That is, the algorithm is initialized by drawing the initial particles from the prior. Likewise, 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 $N = 10,000$ particles and $N_\phi = 200$ stages and set δ at 2 following Herbst and Schorfheide (2015).

To assess the quality of the model's fit to the data we use log marginal data densities and posterior model probabilities for both parametric regions, i.e. determinacy and indeterminacy. The SMC algorithm-based approximation of the marginal data density is given by

$$p^{SMC}(X_T|S) = \prod_{n=1}^{N_\phi} \left(\frac{1}{N} \sum_{i=1}^{N} \widetilde{w}_n^i W_{n-1}^i \right)$$

where $\widetilde{w}_n^i$ is the incremental weight defined by

$$\widetilde{w}_n^i = [p(X|\theta_{n-1}^i, S)]^{\phi_n - \phi_{n-1}}.$$

4.2 Data

We define the set of observables, ϑ_t, which contains quarterly growth rate of real per-capita GDP, consumer price index (CPI), core consumer price index (Core CPI), real wage, and the Federal Funds rate. Wages come from the BLS (hourly compensation for the NFB sector for all persons). Hourly compensation is divided by the CPI in order to get the consumption real wage variable. The measurement equation is

$$\vartheta_t = \begin{bmatrix} g^* \\ \pi^* \\ \pi^* \\ g^* \\ R^* \end{bmatrix} + \begin{bmatrix} \widehat{g}_{y,t} \\ \widehat{\pi}_{c,t} \\ \widehat{\pi}_{q,t} \\ \widehat{g}_{w,t} \\ \widehat{R}_t \end{bmatrix}$$

where g^* is the quarterly steady state net output growth rate, π^* is the steady state net inflation rate, R^* stands for the steady state net interest rate, $\widehat{g}_{y,t}$ 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 (deflated by the consumer price index), and $\widehat{R}_t$ denotes the nominal interest rate. Hatted variables stand for log deviations from the steady state. To test for indeterminacy and estimate the model parameters, we consider two sample periods in our benchmark analysis: 1966:I to 1979:II and 1984:I to 2008:II. We do not demean or detrend any series.

4.3 Calibration

We calibrate a subset of the model parameters. We set the discount factor β 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 first sample and $\alpha = 0.012$ and $\chi = 0.017$ for the second sample. Furthermore, we assume that shocks to the growth rate of technology are i.i.d., i.e. $\rho_z = 0$, since the process already includes a unit root. We also fix the autoregressive parameter of the commodity price shock at $\rho_s = 0.995$, in order to have the commodity price be very close to random walk yet be stationary. In our benchmark estimation, we abstract from price indexation. We estimate all the remaining parameters with Bayesian techniques.

4.4 Prior distributions

The specification of the prior distribution is summarized in Table 1. 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 coefficient to output gap and output growth are centred at 0.125 with standard deviation 0.10. We use Beta distribution with mean 0.50 for the smoothing coefficient ρ_R, the parameter governing the weight on headline inflation in the Taylor rule τ, the Calvo probability ξ, the real wage rigidity γ and habit persistence in consumption h. The prior distribution for the persistence of the discount factor shock and the labor supply shock is also a Beta with mean 0.70 and standard deviation 0.20.

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 oil price shock for which we centre the prior at 5.00 with a standard deviation 2.00 to account for its higher volatility.

Finally, in line with Lubik and Schorfheide (2004), the coefficients M follow standard normal distributions. Hence, the prior is centered around the baseline solution of Lubik and Schorfheide (2004). The choice of the priors leads to a prior predictive probability of determinacy of 0.51, which is quite even and suggests no prior bias toward either determinacy or indeterminacy.

5 Estimation results

5.1 Model comparison

To assess the quality of the model's fit to the data, Table 2 presents marginal data densities and posterior model probabilities for both parametric zones. We find that determinacy unambiguously prevails in both the pre-Volcker and the post-84 sample periods. In other words, the posterior puts all its weight in the determinacy region. The finding that determinacy prevails in both the sample periods might be surprising given that the literature has established the high inflation episode of the 1970s as

Table 1: Prior distributions for parameters

Name	Density	Prior Mean	St. Dev
ψ_π	Gamma	1.10	0.50
ψ_x	Gamma	0.125	0.10
ψ_g	Gamma	0.125	0.10
ρ_R	Beta	0.50	0.20
τ	Beta	0.50	0.20
π^*	Normal	1.00	0.50
R^*	Gamma	1.50	0.25
g^*	Normal	0.50	0.10
ξ	Beta	0.50	0.05
γ	Beta	0.50	0.20
h	Beta	0.50	0.10
ρ_d	Beta	0.70	0.10
ρ_ν	Beta	0.70	0.10
σ_s	Inv-Gamma	5.00	2.00
σ_g	Inv-Gamma	0.50	0.20
σ_r	Inv-Gamma	0.50	0.20
σ_d	Inv-Gamma	0.50	0.20
σ_ν	Inv-Gamma	0.50	0.20
σ_ζ	Inv-Gamma	0.50	0.20
$M_{s,\zeta}$	Normal	0.00	1.00
$M_{g,\zeta}$	Normal	0.00	1.00
$M_{r,\zeta}$	Normal	0.00	1.00
$M_{d,\zeta}$	Normal	0.00	1.00
$M_{\nu,\zeta}$	Normal	0.00	1.00

Notes: 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 while for commodity price shock $\varsigma = 3.81$. The prior probability of determinacy is 0.51.

Table 2: Determinacy versus Indeterminacy

	Log-data density		Probability	
Model	Determinacy	Indeterminacy	Determinacy	Indeterminacy
1966:I-1979:II	-228.89	-241.06	1	0
1984:I-2008:II	-230.03	-251.05	1	0

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

characterized by self-fulfilling inflation expectations. A natural question that arises is: what drives this result?

To shed light on our finding, we would like to start by bridging the gap between the current paper and the existing literature. As such, at first we shut down oil in the model by calibrating the oil share in consumption and production to zero. As a result, the model boils down to a simple GNK model with positive trend inflation ala Ascari and Ropele (2007, 2009) and Ascari and Sbordone (2014). To maintain continuity with the existing literature, we estimate this nested GNK model with only three observables: the quarterly growth rate of real per-capita GDP, the Federal Funds rate and quarterly CPI inflation rate. Moreover, we set the weight τ in the Taylor rule to one as there is just a single concept of inflation in the simple GNK model with no distinction between headline and core. This then makes our set up similar to Hirose, Kurozumi and Van Zandweghe (2017). One exception is that the current paper employs a model with homogenous labor following Ascari and Ropele (2009) and Ascari and Sbordone (2014) while Hirose, Kurozumi and Van Zandweghe (2017) use a model with firm-specific labor following Kurozumi and Van Zandweghe (2017). Table 3 reports the log-data densities while Tables 4 and 5 give the posterior estimates. In line with the findings in the existing literature, the first row in the table confirms that the estimation favors the indeterminate version of the model in the pre-Volcker period.

Having bridged the gap with existing empirical studies, we now sequentially move on by adding one feature at a time. At first, we turn on oil in the model by resetting the values of α and χ to their benchmark calibration. This set up gives us a New Keynesian model with micro-founded cost-push shocks, a feature that is reminiscent of the environment in the 1970s, yet one that is missing in existing empirical investigation on (in)-determinacy. However, we continue to use three observables in our

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

	Log-data density		Probability	
	Det.	Indet.	Det.	Indet.
GNK $(\Delta y_t, R_t, \pi_{c,t})\,[\alpha, \chi = 0; \tau = 1]$	-121.14	-118.81	0.09	0.91
GNK with Oil $(\Delta y_t, R_t, \pi_{c,t})\,[\tau = 1]$	-123.01	-118.28	0.01	0.99
GNK with Oil $(\Delta y_t, R_t, \pi_{c,t}, \pi_{q,t})$	-157.93	-157.56	0.41	0.59
GNK with Oil $(\Delta y_t, R_t, \pi_{c,t}, \pi_{q,t}, \Delta w_t^1)$	-228.89	-241.06	1	0
GNK with Oil $(\Delta y_t, R_t, \pi_{c,t}, \pi_{q,t}, \Delta w_t^1, \Delta w_t^2)$	-279.02	-292.54	1	0

estimation. Furthermore, since we are still using one inflation series as an observable, τ is not identified. Hence, we calibrate this parameter to one such that the central bank responds solely to headline inflation. Once again, indeterminacy unambiguously prevails in the pre-Volcker period.

According to the posterior estimate of the innovation to oil-price shock σ_s, we find that the posterior is virtually indistinguishable from the prior suggesting possible identification issues. In fact, using only one inflation measure as an observable, i.e. CPI inflation alone in this case, does not provide sufficient information to pin down oil-price shocks. Hence, in our next exercise, we simultaneously treat both headline and core inflation as observables. Thus, our dataset now includes four variables. This step enables us to properly identify the oil-price shocks (or more generally commodity price shocks). Also, we estimate the weight τ in the Taylor rule which is now supposedly identified. Table 3 (third row) shows that the finding is now ambiguous: the probability of indeterminacy is 0.59. Phrased alternatively, we can neither rule in nor rule out indeterminacy. Moreover, as anticipated, the innovation to the oil-price shock σ_s is now better identified. Table 4 shows that the posterior mean estimate is significantly higher than the estimate we obtain when using only three observables.

A key parameter in this model is the degree of real wage rigidity γ. As Blanchard and Galí (2007, 2010) argue, the presence of real wage rigidity generates a trade-off between stabilizing inflation and stabilizing the output gap. Accordingly, higher real wage rigidity generates a more severe trade-off. To sharpen the identification of this feature, we next add real wage data, i.e. we employ five observables to estimate the model. We use observations on "hourly compensation for the non-farm business sector for all persons" as a measure of nominal wages. To get real wages, we then divide this proxy by the CPI price deflator. This then gives us our benchmark setup. The fourth row in Table 3 reproduces the log-data densities and posterior model probabilities from Table 2 for the pre-Volcker period. As argued above, the pre-Volcker period is then explicitly characterized by determinacy and a high degree of real wage rigidity.

Our argument can be summarized as follows. It is well known that commodity price shocks in general and oil price shocks in particular were an important source of economic fluctuations in the U.S. during much of the 1970s. For instance, there were episodes of large increases in the price of oil triggered by the Yom Kippur war in 1973 and the Iranian revolution of 1979. Such adverse cost-push shocks generated a trade-off between stabilizing inflation and stabilizing the output gap for the Federal Reserve. Existing empirical investigations on the efficacy of monetary policy in the 1970s find that policy failed to respond sufficiently strongly to inflation thereby generating indeterminacy. However, these studies abstract from modelling the role of commodity price fluctuations and the associated policy trade-off. Our first contribution is to employ a New Keynesian framework with positive trend inflation and an explicit role of oil in both consumption and production. In our framework, we also allow for a mechanism, i.e. the presence of real wage rigidity, which generates a quantitatively meaningful trade-off faced by the central bank following commodity price shocks. Our second contribution is to test for indeterminacy by estimating this model over the Great Inflation and the Great Moderation period. In this endeavor, what further sets us apart from existing empirical work is that we pay particular attention in identifying key features of the model through careful elucidation of observables. Our finding that determinacy prevails in the pre-Volcker period, therefore, rules out self-fulfilling inflation expectations or sunspots as an explanation of the high inflation episode in the 1970s.

As illustrated above, we follow Blanchard and Galí (2007, 2010) and Blanchard and Riggi (2013) by assuming real wage rigidities as a source of real imperfection which breaks down the divine coincidence with respect to commodity price shocks. In our empirical investigation, we find that real wage rigidity turns out to be significantly higher when we allow for wage data in the estimation and the parameter estimates of the Taylor rule turn out to be such that the data explicitly favors determinacy. However, as pointed out by Blanchard and Galí (2007, 2010), this way of modelling real wage rigidity is admittedly ad hoc but still a parsimonious way of capturing slow adjustment of real wages to labor market conditions arising due to some (unmodelled) labor market imperfection or friction. Nonetheless, the fact that we match a particular empirical wage inflation series to the latent concept of wage inflation in the model might have some bearing for the higher posterior estimate of the real wage rigidity parameter γ. In this line of thinking, we next depart from the assumption that wage inflation in the model is measured by a single series and draw on the methodology proposed by Boivin and Giannoni (2006) and recently adopted by Gali, Smets and Wouters (2011) and Justiniano, Primiceri and Tambalotti (2013). We match the wage inflation variable in the model with two data series. The first series is the same one as used in the estimations so far, i.e. "hourly compensation for the non-farm business sector for all employees". The second measure is the "average hourly earnings of production and non-supervisory employees". Following Justiniano, Primiceri and Tambalotti (2013), we further assume that both series represent an imperfect match to the concept of "wage" in the model and capture this mismatch through i.i.d. measurement errors. This assumption is important as Justiniano, Primiceri and Tambalotti (2013) find that most of the high frequency variation that characterizes the individual series on compensation is due to measurement error. More concretely, the estimation involves the following measurement equation for wage inflation

$$\begin{bmatrix} \Delta \log NHC_t \\ \Delta \log HE_t \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \end{bmatrix} g^* + \begin{bmatrix} 1 \\ \lambda \end{bmatrix} \widehat{g}_{w,t} + \begin{bmatrix} e_{1,t} \\ e_{2,t} \end{bmatrix}$$

where $\Delta \log NHC_t$ and $\Delta \log HE_t$ denote the growth rate of the two measures of wages in the data (deflated using CPI), λ is a loading coefficient relating the second series to the latent concept of wage inflation in the model, and $e_{1,t}$ and $e_{2,t}$ are i.i.d. observation errors with distribution $N(0, \sigma_{e_1}^2)$ and $N(0, \sigma_{e_2}^2)$.[5] Our prior distributions for the loadings and measurement equations are $\lambda \sim N(1.00, 0.50)$ and $\sigma_{e_1}, \sigma_{e2} \sim IG(0.10, 0.20)$. Once again, the degree of real wage rigidity turns out to be substantially higher and as a corollary determinacy unambiguously prevails in the pre-Volcker period.

5.2 Parameter estimates

Tables 4 and 5 report the posterior mean and the standard deviation of the parameters under alternative specifications for the pre-1979 and the post-1984 sample periods respectively. First of all, we find that the estimated response to inflation in the Taylor rule is passive for the GNK model estimated using three observables and for

[5] The other loading is normalized to 1 as standard in factor analysis.

the model with oil estimated using either three or four observables. This finding is in line with the literature's view that the policy response to inflation was passive during the Great Inflation period. However, once we allow for wage data in our estimation (either using just one wage series or using two series following Boivin and Giannoni's (2006) methodology), we find the degree of real wage rigidity to be significantly higher: the point estimate turns out to be around 0.9. As argued above, such a high degree of real wage rigidity worsens the trade-off faced by the central bank in the wake of commodity price shocks. Now the estimated response to inflation now turns out to be active during the pre-1979 period. Moreover, the response to output gap turns out to be substantially lower while the response to output growth and the degree of policy-rate smoothing turns out to be higher. This finding confirms our intuition that the parameter estimates of the Taylor rule during the pre-Volcker period might possibly be biased if the empirical investigation does not take into account the effect of commodity price shocks and the associated trade-offs faced by the central bank. Combined together, such changes in the parameter estimates of the Taylor rule push the posterior distribution toward the determinacy region of the parameter space.

Moving across the sample period while focusing on the parameter estimates of the GNK model with oil estimated using six observables (i.e. two wage series), we see that the policy response to inflation and output growth almost doubled while trend inflation fell considerably. The Federal Reserve also moved its focus away from responding to headline inflation during the pre-1979 period toward core inflation during the post-1984 period. Among the other structural parameters, habit persistence in consumption decreased slightly while the degree of price stickiness remained roughly unchanged. Furthermore, qualitatively in line with the findings of Blanchard and Riggi (2013), we find a substantial decline in real wage rigidity. However, our estimate still points toward the presence of moderate degree of rigidity while Blanchard and Riggi (2013) document perfect real wage flexibility. This divergence might be due to the different estimation strategies that we employ. While Blanchard and Riggi (2013) adopt a limited information approach that matches impulse responses to an oil price shock in the DSGE model and in a structural VAR, we use full-information Bayesian estimation with multiple shocks.

In terms of the standard deviations of the innovations, there is an increase in the volatility of commodity price shock and labor supply shock. As argued by Blanchard and Galí (2010), the increase in the size of commodity price shock is due to its limited variation before the 1973 crisis, despite the two large spikes in that year. On

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

	GNK (Indet) 3 obs	GNK-Oil (Indet) 3 obs	GNK-Oil (Indet) 4 obs	GNK-Oil (Det) 5 obs	GNK-Oil (Det) 6 obs
ψ_π	0.94 (0.11)	0.94 (0.11)	0.92 (0.12)	1.55 (0.19)	1.51 (0.17)
ψ_x	0.14 (0.11)	0.21 (0.14)	0.30 (0.11)	0.03 (0.02)	0.03 (0.03)
ψ_g	0.11 (0.07)	0.12 (0.07)	0.10 (0.05)	0.46 (0.16)	0.35 (0.14)
ρ_R	0.44 (0.08)	0.48 (0.08)	0.60 (0.10)	0.71 (0.05)	0.69 (0.05)
τ	1	1	0.35 (0.24)	0.57 (0.16)	0.58 (0.15)
π^*	1.42 (0.18)	1.34 (0.21)	1.37 (0.13)	1.36 (0.16)	1.36 (0.17)
R^*	1.56 (0.17)	1.51 (0.18)	1.58 (0.13)	1.52 (0.20)	1.51 (0.20)
g^*	0.48 (0.09)	0.51 (0.09)	0.50 (0.06)	0.47 (0.07)	0.45 (0.07)
ξ	0.50 (0.05)	0.54 (0.05)	0.66 (0.06)	0.62 (0.04)	0.60 (0.04)
γ	0.50 (0.24)	0.33 (0.17)	0.64 (0.25)	0.90 (0.03)	0.89 (0.04)
h	0.40 (0.07)	0.37 (0.07)	0.37 (0.05)	0.39 (0.07)	0.38 (0.07)
ρ_d	0.78 (0.08)	0.70 (0.10)	0.62 (0.09)	0.76 (0.06)	0.77 (0.07)
ρ_ν	–	0.69 (0.10)	0.67 (0.09)	0.80 (0.07)	0.86 (0.07)
σ_s	–	5.34 (2.23)	17.30 (1.38)	17.30 (1.62)	17.24 (1.62)
σ_g	1.59 (0.22)	1.51 (0.21)	0.80 (0.38)	0.63 (0.06)	0.48 (0.09)
σ_r	0.31 (0.04)	0.30 (0.03)	0.25 (0.04)	0.31 (0.04)	0.30 (0.03)
σ_d	0.54 (0.18)	0.39 (0.13)	1.57 (0.59)	1.94 (0.35)	1.86 (0.33)
σ_ν	–	0.36 (0.11)	0.62 (0.17)	0.41 (0.08)	0.38 (0.08)
σ_ζ	0.50 (0.27)	0.46 (0.20)	0.52 (0.20)	–	–
$M_{s,\zeta}$	–	-1.19 (0.58)	-0.07 (0.18)	–	–
$M_{g,\zeta}$	0.66 (0.86)	0.81 (0.70)	-0.14 (0.69)	–	–
$M_{r,\zeta}$	0.16 (0.97)	0.36 (1.00)	0.31 (0.74)	–	–
$M_{d,\zeta}$	0.13 (1.07)	-0.08 (1.02)	0.95 (1.09)	–	–
$M_{\nu,\zeta}$	–	-0.23 (1.01)	0.11 (0.93)	–	–
λ	–	–	–	–	1.07 (0.24)
σ_{e_1}	–	–	–	–	0.37 (0.10)
σ_{e_2}	–	–	–	–	0.46 (0.10)

Table 5: Parameter Estimates (1984:I-2008:II)

	GNK (Det) 3 obs	GNK-Oil (Det) 3 obs	GNK-Oil (Det) 4 obs	GNK-Oil (Det) 5 obs	GNK-Oil (Det) 6 obs
ψ_π	2.38 (0.34)	2.35 (0.32)	2.43 (0.24)	2.25 (0.30)	3.08 (0.36)
ψ_x	0.11 (0.09)	0.11 (0.09)	0.16 (0.13)	0.02 (0.01)	0.11 (0.06)
ψ_g	0.67 (0.20)	0.71 (0.21)	0.60 (0.14)	1.19 (0.20)	0.69 (0.15)
ρ_R	0.79 (0.03)	0.80 (0.03)	0.69 (0.04)	0.78 (0.03)	0.73 (0.04)
τ	1	1	0.22 (0.07)	0.23 (0.09)	0.14 (0.05)
π^*	0.83 (0.07)	0.84 (0.08)	0.84 (0.07)	1.01 (0.09)	0.95 (0.09)
R^*	1.39 (0.14)	1.40 (0.14)	1.43 (0.13)	1.53 (0.15)	1.44 (0.14)
g^*	0.51 (0.06)	0.51 (0.06)	0.50 (0.06)	0.38 (0.07)	0.16 (0.05)
ξ	0.47 (0.04)	0.49 (0.04)	0.65 (0.04)	0.80 (0.03)	0.62 (0.04)
γ	0.18 (0.10)	0.16 (0.09)	0.18 (0.11)	0.81 (0.07)	0.46 (0.12)
h	0.36 (0.06)	0.36 (0.06)	0.20 (0.04)	0.28 (0.06)	0.24 (0.05)
ρ_d	0.91 (0.02)	0.91 (0.02)	0.90 (0.04)	0.88 (0.03)	0.85 (0.04)
ρ_ν	–	0.71 (0.10)	0.72 (0.12)	0.94 (0.02)	0.99 (0.01)
σ_s	–	3.75 (1.10)	20.17 (1.40)	20.23 (1.42)	20.41 (1.50)
σ_g	0.76 (0.08)	0.76 (0.08)	0.66 (0.08)	0.83 (0.06)	0.44 (0.08)
σ_r	0.21 (0.02)	0.20 (0.02)	0.19 (0.02)	0.17 (0.02)	0.17 (0.02)
σ_d	1.50 (0.27)	1.50 (0.28)	1.33 (0.24)	1.40 (0.24)	1.23 (0.19)
σ_ν	–	0.35 (0.10)	0.36 (0.12)	0.55 (0.12)	0.75 (0.15)
λ	–	–	–	–	0.29 (0.08)
σ_{e_1}	–	–	–	–	0.66 (0.07)
σ_{e_2}	–	–	–	–	0.38 (0.04)

the other hand, the innovation variance of monetary policy shock and discount factor shock declined quite notably while the size of the technology shock remained fairly stable.

Finally, there is a substantial change in the estimate of the loading coefficient λ. In the pre-Volcker period, the estimate of λ is quite close to one implying a similarity in the two wage inflation series during that period. However, in the post-1984 period, it turns out to be much lower: the posterior mean estimate is 0.29. This further justifies the differences in some of the parameter estimates of the model for the post-1984 period depending on whether we employ the first empirical series alone as in our five observables case versus when we use both wage inflation series as in the six observables case.

5.3 Implications of the model for macroeconomic volatility

In this section, we assess the ability of the model to account for the Great Moderation, i.e. the marked decline in macroeconomic volatility in the second sub-sample. Table 6 summarizes the model's implications for the volatility of the inflation (both headline and core) and output growth at the posterior mean of the model parameters along with the data-based standard deviations over the indicated sample. The estimated model is able to replicate the observed drop in volatility.[6] We find a fall of output growth variability of 45% and a drop of headline and core inflation volatility of about 56% and 70% respectively. The figures are similar to those reported in the literature. For instance, Justiniano and Primiceri (2008) report a fall of output growth variability of about 25% and a drop of inflation variability of about 75%. The numbers in Smets and Wouters (2007) read 35% and 58% respectively. Despite the fact that our model is relatively small-scale in nature compared to the medium-scale models in these studies, we find it reassuring in terms of the empirical plausibility of our estimation results.

6 Trade-off between inflation and output gap stabilization

In this section, we illustrate the importance of real wage rigidity in generating a quantitatively meaningful trade-off faced by the central bank in stabilizing inflation

[6] Although it overestimates the standard deviation, such mismatch is also present in medium-scale models as well. See Smets and Wouters (2007).

Table 6: The Great Moderation

	1966:I-1979:II		1984:I-2008:II		Percent Change	
	Data	Model	Data	Model	Data	Model
Headline Inflation	0.68	1.04	0.38	0.46	-44%	-56%
Core Inflation	0.60	0.89	0.28	0.27	-53%	-70%
Output Growth	1.01	1.14	0.53	0.63	-48%	-45%

and output gap volatility in the wake of commodity price shocks. Figure 1 plots the impulse responses of headline inflation, core inflation, the welfare-relevant output gap and price dispersion to a one standard deviation commodity price shock under three alternative calibration of the real wage rigidity parameter. The structural parameters as well as the policy parameters are calibrated to their estimated posterior mean values for the pre-1979 period.

First of all, we see that in the absence of real wage rigidity, headline inflation increases while there is a decrease in core inflation, the output gap and price dispersion. The rise in headline inflation is somewhat obvious since part of the increase in oil prices is reflected mechanically in the oil component of the CPI. On the other hand, there is a reduction in core inflation owing to our assumption of real wage flexibility. With perfectly flexible real wages, an increase in the real price of oil reduces the consumption real wage and hence lowers the marginal cost. As a result, there is a fall in desired price as well as price dispersion. Moreover, the output gap goes down as well. To the extent that the central bank's objective is to stabilize both headline inflation as well as welfare-relevant output gap, it faces a trade-off even in the absence of real wage rigidity. However, divine coincidence holds when the central bank focuses on stabilizing core inflation instead as both output gap and core inflation goes down. In fact, one might argue that core inflation is a more natural reference point for monetary policy as policy can only affect the sticky price component. Hence, we qualify the results documented in Alves (2014) who argues that a non-zero steady state level of inflation makes it impossible for monetary policy to simultaneously stabilize inflation and output gap in response to preference and technology shocks. In any case, the response of the endogenous variables to a commodity price shock is quantitatively negligible when γ is set equal to zero.

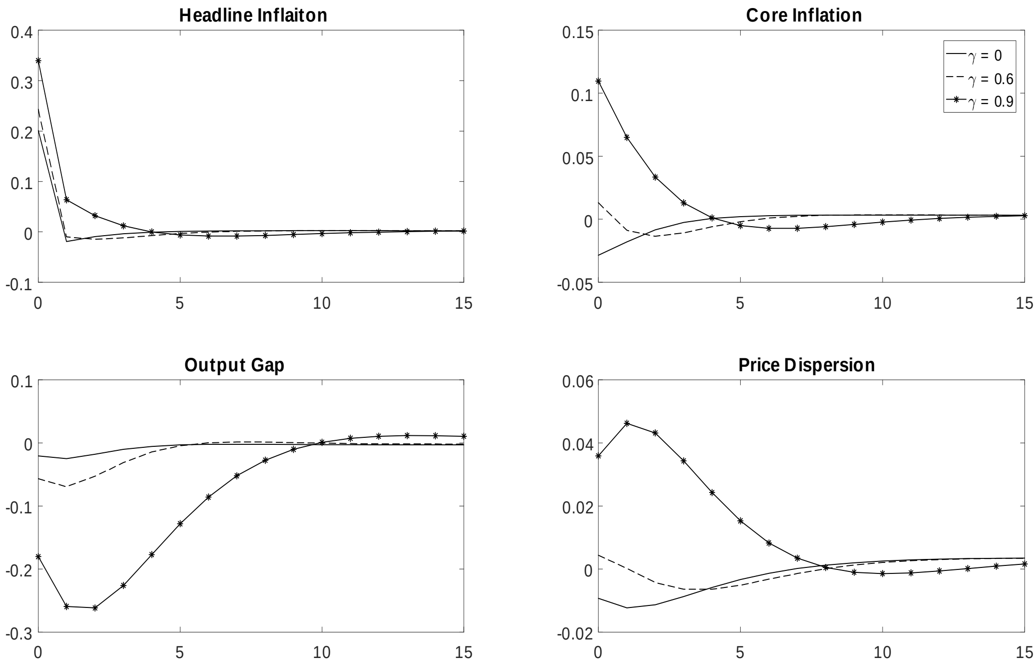

Figure 1

In contrast, for high levels of real wage stickiness, policymakers face a quantitatively meaningful trade-off between output gap and inflation (either headline or core) stabilization. This trade-off arises from the fact that even in the equilibrium in which output gap is stabilized, desired prices are not constant in general. With real wages being rigid, an increase in the real price of oil will result in an increase in the firm's marginal cost, and hence in both desired price and core inflation. Due to fluctuations in desired prices, firms that reset their prices in different periods will charge different prices. This resulting increase in price dispersion will lead to instability in price inflation. Therefore, higher real wage rigidity generates a more severe trade-off faced by the central bank in the aftermath of commodity price shocks. A stable welfare-relevant output gap is thus inconsistent with either stable headline and/or core inflation. As such, the parameter estimates of the Taylor rule during the 1970s might possibly be biased if the empirical investigation leaves out real wage rigidity and the associated trade-off faced by the Federal Reserve in the wake of commodity price shocks.

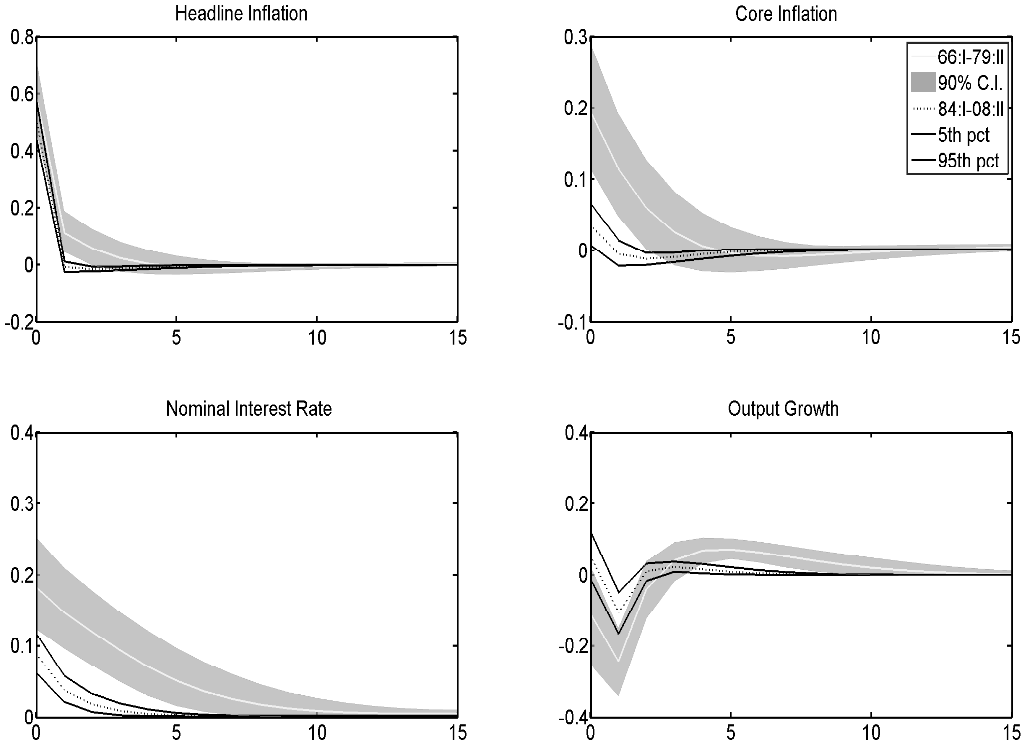

Figure 2

7 Propagation of commodity price shock

This section studies the propagation of commodity price shock as well as how it has changed over time. Figure 2 depicts the estimated mean impulse responses of headline inflation, core inflation, nominal interest rate and output growth for both sample periods along with the 90 percent probability interval. As evident from the figure, the effects of commodity price shocks have changed significantly over time. Our estimates point to much smaller effects on core inflation, real activity and interest rate in the second sub-sample despite the fact that the shocks are slightly larger in size. The only exception is the response of headline inflation, whose impact response is very similar, albeit with a reduced 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. This finding is reassuring as it matches with the empirical VAR evidence put forth by Blanchard and Gali (2010) and Blanchard and Riggi (2013).

Next , we conduct counterfactual experiments to disentangle the driving force behind these changes over time. We divide the experiments into two categories.

First, we combine the posterior mean estimates pertaining to the Taylor rule, i.e. $\psi_\pi, \psi_x, \psi_{\Delta y}, \rho_R, \pi^*, \tau$, of the post-1984 sub-sample with the remaining parameter estimates of the pre-1979 period which is called 'post-84 policy'. This exercise is designed to capture the role of monetary policy in the reducing the effect of a given change in commodity prices. In the second category, we combine 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.

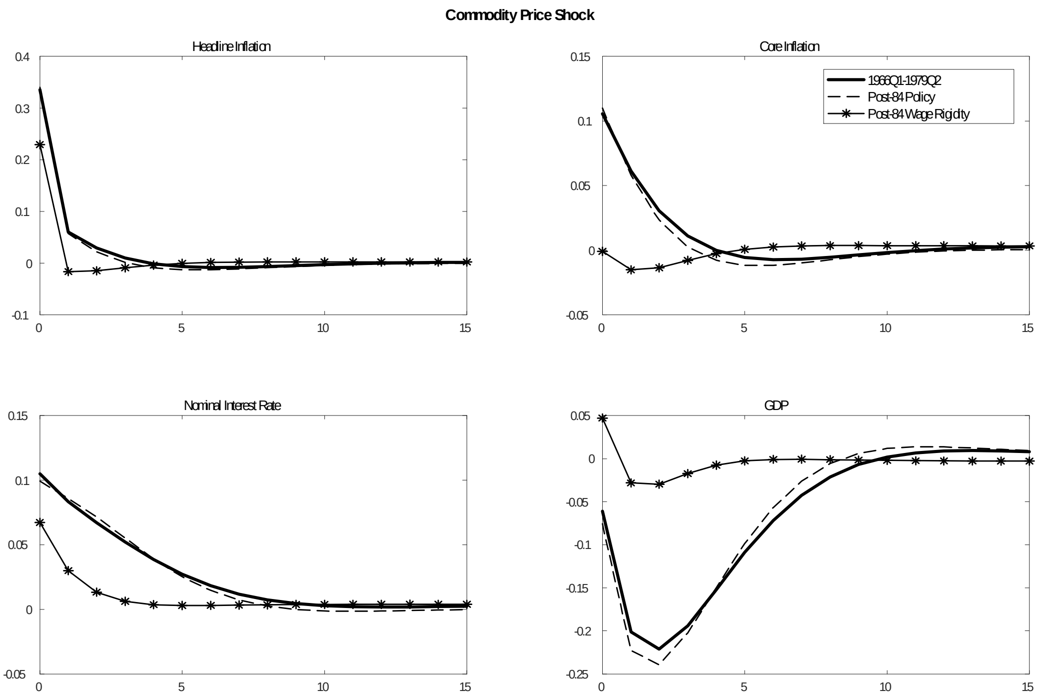

Figure 3

Figure 3 depicts the impulse responses to a one standard deviation commodity price shock under the two alternative scenarios while calibrating the remaining parameters at the posterior mean estimates of the pre-1979 period. Looking at the figure, we can see that the decline in the effects of commodity price shocks is mainly explained by a reduction in real wage rigidity. As argued earlier, real wage rigidity generates a trade-off between inflation and output gap stabilization. A shift toward more flexible wages implies a reduction in this trade-off thereby explaining the smaller effects of the shocks in the more recent period. Thus, our finding corroborates one of the hypothesis put forth by Blanchard and Gali (2010) and is also in line with the empirical evidence documented in Blanchard and Riggi (2013).

8 Sensitivity analysis

We now conduct sensitivity of our results in various directions that involve (i) indexation to past inflation, (ii) alternative Taylor rule, (iii) alternative formulation of the boundary between the determinacy and indeterminacy region, (iv) flexible-price output gap, (v) estimation over the entire parameter space, and (vi) real oil price as an observable. For all these cases, the estimation is conducted using six observables, i.e. including both wage series ala Boivin and Giannoni (2006). Table 7 reports the log-data densities and the posterior probabilities while the parameter estimates are reported in Tables A1 and A2 in the appendix.

8.1 Indexation

In light of the result of Cogley and Sbordone (2008) regarding the lack of empirical support for intrinsic inertia in the generalized New Keynesian Phillips Curve, the model is so far estimated by assuming absence of rule-of-thumb price-setting. Hence, we now estimate the model while allowing for indexation. To facilitate identification, we follow Ascari, Castelnuovo and Rossi (2011) by calibrating the relative degree of indexation μ to one and estimating the degree of indexation to past inflation ω in line with Benati (2009). While we find some support for moderate degree of indexation, our finding that the pre-Volcker period is characterized by determinacy remains robust.

8.2 Alternative Taylor rule

Next we investigate the sensitivity of our findings with respect to an alternative formulation of the monetary policy rule. Following Justiniano, Primiceri and Tambalotti (2013), the specification of the rule now features a systematic response to deviations of annual inflation from a positive constant trend inflation (featuring weighted response to both headline and core inflation) and to deviations of observed annual GDP growth from its steady state level.[7] It also includes interest rate smoothing and response to welfare-relevant output gap as before. Thus, we re-estimate the model by replacing the standard policy rule with the following formulation:

[7] Strictly speaking, Justiniano, Primiceri and Tambalotti (2013) consider deviations of annual inflation from a time-varying inflation target.

Table 7: Determinacy versus Indeterminacy (Robustness)

		Log-data density		Probability	
		Det.	Indet.	Det.	Indet.
1966:I-1979:II	Indexation	-277.70	-291.52	1	0
	JPT Taylor rule	-286.71	-292.01	1	0
	Boundary	-279.02	-282.33	0.96	0.04
	Flex-price Output Gap	-276.25	-285.12	1	0
	Entire Parameter Space	-279.27		1	0
	Core CPI & Oil	-504.85	-515.42	1	0
1984:I-2008:II	Indexation	-287.87	-342.15	1	0
	JPT Taylor rule	-281.56	-317.89	1	0
	Boundary	-275.20	-361.36	1	0
	Flex-price Output Gap	-280.87	-312.90	1	0
	Entire Parameter Space	-275.71		1	0
	Core CPI & Oil	-619.62	-658.99	1	0

$$R_t = \widetilde{R}_t^{1-\rho_R} R_{t-1}^{\rho_R} \exp\{\sigma_R \varepsilon_{R,t}\},$$

with

$$\widetilde{R}_t = \overline{R} \left\{ \left(\frac{\left(\Pi_{s=0}^{3} \pi_{c,t-s}\right)^{1/4}}{\overline{\pi}} \right)^{\tau} \left(\frac{\left(\Pi_{s=0}^{3} \pi_{q,t-s}\right)^{1/4}}{\overline{\pi}} \right)^{1-\tau} \right\}^{\psi_\pi} \left\{ \frac{x_t}{\overline{x}} \right\}^{\psi_x} \left\{ \frac{\left(Y_t / Y_{t-1}\right)^{1/4}}{\overline{g}} \right\}^{\psi_{\Delta y}}.$$

We find a stronger response to output growth in both periods which is somewhat similar in magnitude to what Justiniano, Primiceri and Tambalotti (2013) reports. Other than this, the remaining results remain quite robust.

8.3 Boundary

As discussed earlier, the presence of positive trend inflation enriches the dynamics of the model and the usual Taylor principle ($\psi_\pi > 1$) is no longer a sufficient condition for local determinacy of equilibrium. Due to the higher-order dynamics, it is not feasible to analytically derive the indeterminacy conditions. To continue solving the model via Lubik and Schorfheide's (2004) continuity solution (where $M^*(\theta)$ is selected such that the responses of the endogenous variables to the fundamental shocks are continuous at the boundary between the determinacy and indeterminacy region) one needs to resort to numerical methods. In our applications so far, we follow Justiniano and Primiceri (2008) and Hirose (2014) by perturbing the response to inflation ψ_π in the monetary policy rule to numerically trace the boundary. However, due to the presence of trend inflation, the boundary becomes a complicated function of ψ_π along with other Taylor rule and structural parameters. As such, the (in-)determinacy test might be susceptible to how we trace the boundary. Hence, as an alternative, we now drag both the response to inflation ψ_π as well as the response to output gap ψ_x. This then possibly gets us to a different region of the boundary in the parameter space. Nonetheless, we still find that the data favors determinacy and the response to inflation is active even during the Great Inflation period.

8.4 Flexible-price output gap

We have argued earlier that allowing for wage data in the estimation helps us account for the higher real wage rigidity in the 1970s and generates a quantitatively meaningful trade-off faced by the central bank in the model economy. In the face of such trade-offs, our posterior estimates suggest an active response to inflation and a virtually negligible response to output gap during the pre-Volcker period which combined together push the posterior toward the determinacy region. In line with Blanchard and Riggi (2013), we have focused on welfare-relevant output gap, defined as the gap between actual and efficient output. Blanchard and Riggi (2013) justify their assumption by arguing that natural or potential level of output may move a lot with respect to oil price shock in a model with real wage rigidities whereas the efficient or welfare-relevant output moves much less, looks like a smooth time trend and appears to be what the Federal Reserve looks at. However, one could rightfully argue that natural or potential output is a better reference point for monetary policy as monetary policy is neutral in the long run and thus cannot offset fluctuations in the welfare-relevant output gap. As such, we replace the efficient output gap with the flexible-price output gap, defined as the gap between actual and potential output. We find that the estimate of the response to output gap during the pre-1979 period turns out to be somewhat higher this time. Yet, the findings that the pre-Volcker period is characterized by determinacy and active response to inflation remain unchanged.

8.5 Estimation over the entire parameter space

In our applications so far, follow Lubik and Schorfheide (2004) and estimate the model twice, first under determinacy, then under indeterminacy. While Lubik and Schorfheide (2004) possibly did so because of the sampling technology available back then which was Random Walk Metropolis Hastings algorithm, an importance sampling algorithm like SMC can use a single chain instead to explore the entire parameter space. Hence, to take full advantage of this algorithm, we now estimate the model simultaneously over both determinacy and indeterminacy region following Hirose, Kurozumi and Van Zandweghe (2017). The likelihood function is then given by

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

where Θ^D, Θ^I are the determinacy and indeterminacy regions of the parameter space, $1\{\theta_S \in \Theta^S\}$ is the indicator function that equals 1 if $\theta_S \in \Theta^S$ and zero otherwise, and $p^D(X_T|\theta_D, D)$, $p^I(X_T|\theta_I, I)$ are the likelihood functions under determinacy and indeterminacy respectively. All our results, including the fit of the model and the parameter estimates, stay unaltered.

8.6 Oil as an observable

Lastly, we investigate the sensitivity of our results to directly using real oil price as an observable. In our effort to pin down the cost-push shocks, until now we have simultaneously employed both headline and core inflation measures as observables. This choice identifies the cost-push shocks as commodity price shocks in general (which includes the price of food and other commodities as well). To the extent that there were other driving forces of inflation in the 1970s other than oil price shocks, using both inflation measures simultaneously is a sound identification strategy. For instance, the two inflationary episodes in the 1970s also featured sizeable food-price hikes as documented by Blinder and Rudd (2012). Since food has a much larger weight in the price indexes than energy, ignoring them might constitute a key omission. Nonetheless, we also check the robustness of our results to directly using percentage change of the real price of oil as an observable to identify the episodes of oil price shocks in isolation. As such, we use the West Texas Intermediate oil price data.[8] We deflate the nominal oil price by the core consumer price index to be in line with the concept of real oil price in the model. The resulting series is then demeaned by it's sub-sample mean prior to estimation. We continue to use data on quarterly growth rate of GDP per capita, core CPI, the two (real) wage inflation series and the Federal Funds rate. Our results still remain robust

9 Conclusion

This paper presents a New Keynesian economy with trend inflation, wage rigidity and oil entering in both consumption and production. While allowing for indeterminacy, we examine the interaction between oil price shocks and monetary policy during the Great Inflation. When considering the model without oil, indeterminacy prevails in the pre-Volcker period while determinacy gets favoured by post-1984 data. We then introduce oil into the economy and evidence for indeterminacy disappears: the pre-Volcker period is unambiguously characterized by a unique rational expectations equilibrium with a high degree of real wage rigidity. In this environment, oil price shocks create an acute trade-off between inflation and output gap stabilization. Faced with this trade-off, we document that the Federal Reserve responded aggressively to inflation and hardly to the output gap and this policy had important implications

[8]Nakov and Pescatori (2010) use this same oil price series in their empirical exercise and find that oil played an important role in the Great Moderation.

for interpreting the Great Inflation. We also estimate the model over the Great Moderation period and document that oil price shocks are no longer as inflationary as they used to be due to lower real wage rigidity, allowing the Federal Reserve to respond less aggressively to a given oil price shock. This result parallels the Blanchard and Galí (2010) hypothesis of a decline in real wage rigidity as a key factor in the remarkable resilience of the U.S. economy to sustained oil price increases in the 2000s.

References

[1] Alves, S. (2014): "Lack of Divine Coincidence in New Keynesian Models", Journal of Monetary Economics 67, 33-46.

[2] Arias, E. , G. Ascari, N. Branzoli and E. Castelnuovo (2017): "Positive Trend Inflation and Determinacy in a Medium-Sized New-Keynesian Model", Federal Reserve Bank of Philadelphia, mimeo.

[3] Ascari, G., E. Castelnuovo and L. Rossi (2011): "Calvo vs. Rotemberg in a Trend Inflation World: An Empirical Investigation", Journal of Economic Dynamics and Control 35, 1852-1867.

[4] Ascari, G. and T. Ropele (2007): "Optimal Monetary Policy under Low Trend Inflation", Journal of Monetary Economics 54, 2568-2583.

[5] Ascari, G. and T. Ropele (2009): "Trend Inflation, Taylor Principle, and Indeterminacy", Journal of Money, Credit and Banking 41, 1557-1584.

[6] Ascari, G. and A. Sbordone (2014): "The Macroeconomics of Trend Inflation", Journal of Economic Literature 52, 679-739.

[7] Barsky, R. and L. Kilian (2002): "Do We Really Know that Oil Caused the Great Stagflation? A Monetary Alternative", in: Bernanke, B. and K. Rogoff (editors), NBER Macroeconomics Annual 16, MIT Press, Cambridge, 137-183.

[8] Benati, L. (2009): "Are 'Intrinsic Inflation Persistence' Models Structural in the Sense of Lucas (1976)?", European Central Bank Working Paper No. 1038.

[9] Benati, L. and P. Surico (2009): "VAR Analysis and the Great Moderation", American Economic Review 99, 1636-1652.

[10] Bernanke, B., M. Gertler and M. Watson (1997): "Systematic Monetary Policy and the Effects of Oil Price Shocks", Brookings Papers on Economic Activity 1997, 91-157.

[11] Bilbiie, F. and R. Straub (2013): "Asset Market Participation, Monetary Policy Rules, and the Great Inflation", Review of Economics and Statistics 95, 377-392.

[12] Blanchard, O. and J. Galí (2007): "Real Wage Rigidities and the New Keynesian Model", Journal of Money, Credit and Banking 39, 35-65.

[13] Blanchard, O. and J. Galí (2010): "The Macroeconomic Effects of Oil Price Shocks: Why are the 2000s so different from the 1970s?", in: Galí, J. and M. Gertler (editors), International Dimensions of Monetary Policy, University of Chicago Press, Chicago, 373-428.

[14] Blanchard, O. and M. Riggi (2013): "Why are the 2000s so Different from the 1970s? A Structural Interpretation of Changes in the Macroeconomic Effects of Oil Prices", Journal of the European Economic Association 11, 1032-1052.

[15] Blinder, A. and J. Rudd (2012): "The Supply-shock Explanation of the Great Stagflation Revisited", in: Bordo M. and A. Orphanides (editors), The Great Inflation: The rebirth of modern central banking, University of Chicago Press, Chicago, 119-175.

[16] Boivin, J. and M. Giannoni (2006): "DSGE Models in a Data-rich Environment", NBER Working Paper No. 12772.

[17] Clarida, R., J. Galí and M. Gertler (2000): "Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory", Quarterly Journal of Economics 115, 147-180.

[18] Cogley, T. and A. Sbordone (2008): "Trend Inflation, Indexation, and Inflation Persistence in the New Keynesian Phillips Curve", American Economic Review 98, 2101-2126.

[19] Coibion, O. and Y. Gorodnichenko (2011): "Monetary Policy, Trend Inflation, and the Great Moderation: An Alternative Interpretation", American Economic Review 101, 341-370.

[20] Doko Tchatoka, F., N. Groshenny, Q. Haque and M. Weder (2017): "Monetary Policy and Indeterminacy after the 2001 Slump", Journal of Economic Dynamics and Control 82, 83-95.

[21] Fujiwara, I. and Y. Hirose (2014): "Indeterminacy and Forecastability", Journal of Money, Credit and Banking 46, 243-251.

[22] Galí, J., F. Smets and R. Wouters (2012): "Unemployment in an Estimated New Keynesian Model", NBER Macroeconomics Annual 26, 329-360.

[23] Hamilton, J. (1983): "Oil and the Macroeconomy since World War II", Journal of Political Economy 91, 228-248.

[24] Haque, Q. (2017): "Monetary Policy, Inflation Target and the Great Moderation: An Empirical Investigation", School of Economics Working Paper No. 2017-13, The University of Adelaide.

[25] Herbst, E. and F. Schorfheide (2014): "Sequential Monte Carlo Sampling for DSGE Models", Journal of Applied Econometrics 29, 1073-1098.

[26] Herbst, E. and F. Schorfheide (2015): "Bayesian Estimation of DSGE Models". Princeton University Press.

[27] Hirose, Y. (2007): "Sunspot Fluctuations under Zero Nominal Interest Rates", Economics Letters 97, 39-45.

[28] Hirose, Y. (2008): "Equilibrium Indeterminacy and Asset Price Fluctuation in Japan: A Bayesian Investigation", Journal of Money, Credit and Banking 40, 967-999.

[29] Hirose, Y. (2013): "Monetary Policy and Sunspot Fluctuations in the United States and the Euro area", Macroeconomic Dynamics 17, 1-28.

[30] Hirose, Y. (2014): "An Estimated DSGE Model with a Deflation Steady State", Working Paper Series 52/2014, Centre for Applied Macroeconomic Analysis, Australian National University.

[31] Hirose, Y., Y. Kurozumi and W. Van Zandweghe (2017): "Monetary Policy and Macroeconomic Stability Revisited", Working Paper Series 38/2017, Centre for Applied Macroeconomic Analysis, Australian National University.

[32] Hornstein, A. and A. Wolman (2005): "Trend Inflation, Firm-Specific Capital, and Sticky Prices", Federal Reserve Bank of Richmond Economic Quarterly 91, 57–83.

[33] Justiniano, A. and G. Primiceri (2008): "The Time-varying Volatility of Macroeconomic Fluctuations", American Economic Review 98, 604-641.

[34] Justiniano, A., G. Primiceri and A. Tambalotti (2013): "Is There a Trade-off Between Inflation and Output Stabilization?", American Economic Journal: Macroeconomics 5, 1-31.

[35] Kiley, M. (2007): "Is Moderate-to-High Inflation Inherently Unstable?", International Journal of Central Banking 3, 173–201.

[36] Kurozumi, T. and W. Van Zandweghe (2017): "Trend Inflation and Equilibrium Stability: Firm-Specific Versus Homogeneous Labor", Macroeconomic Dynamics 21, 947-981.

[37] Lubik, T. and F. Schorfheide (2003): "Computing Sunspot Equilibria in Linear Rational Expectations Models", Journal of Economic Dynamics and Control 28, 273-285.

[38] Lubik, T. and F. Schorfheide (2004): "Testing for Indeterminacy: An Application to US Monetary Policy", American Economic Review 94, 190-217.

[39] Nakov, A. and A. Pescatori (2010): "Oil and the Great Moderation", Economic Journal 120, 131-156.

[40] Natal, J. (2012): "Monetary Policy Response to Oil Price Shocks", Journal of Money, Credit and Banking 44, 53-101.

[41] Orphanides, A (2004): "Monetary Policy Rules, Macroeconomic Stability, and Inflation: A View from the Trenches", Journal of Money, Credit, and Banking 36, 151-175.

[42] Smets, F. and R. Wouters (2007): "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach", American Economic Review 97, 586-606.

[43] Taylor, J. (1993): "Discretion versus Policy Rules in Practice", Carnegie-Rochester Conference Series on Public Policy 39, 195-214.