Economics Working Papers

2020-10

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

Qazi Haque, Nicolas Groshenny and Mark Weder

AARHUS BSS
DEPARTMENT OF ECONOMICS AND BUSINESS ECONOMICS
AARHUS UNIVERSITY

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

Qazi Haque*
University of Western Australia and CAMA

Nicolas Groshenny†
University of Adelaide and CAMA

Mark Weder‡
Aarhus University and CAMA

August 13, 2020

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**.

*Department of Economics, University of Western Australia, 35 Stirling Hwy, Crawley WA 6009, Australia. Email: qazi.haque@uwa.edu.au.

†School of Economics, University of Adelaide, 10 Pulteney Street, Adelaide SA 5005, Australia. Email: nicolas.groshenny@adelaide.edu.au

‡Department of Economics and Business Economics, Aarhus University, Fuglesangs Allé 4, 8210 Aarhus V, Denmark. Email: mweder@econ.au.dk (*corresponding author*)

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 fifteen percent. This period was followed by pronounced moderations in volatilities. Since the seminal works by Clarida et al. (2000) and Lubik and Schorfheide (2004), a dominant narrative of the Great Inflation 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 volatility. The subsequent shift to an active policy, brought about during the terms of Chairmen Volcker and Greenspan, thenceforth removed sunspot instability and thus stabilized inflationary expectations.[1] 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.[2] Such cost-push shocks arguably generated a trade-off between stabilizing inflation and the output gap for the Federal Reserve, a trade-off absent from the more recent studies of the Great Inflation that focus on the interplay of monetary policy and indeterminacy.

This paper re-examines the role of monetary policy during the Great Inflation 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 (Bruno and Sachs, 1985, 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

[1] An alternative explanation, dubbed the "good luck", emphasizes a change in the volatility of shocks hitting the economy (Primiceri, 2005; Sims and Zha, 2006; Smets and Wouters, 2007; and Justiniano and Primiceri, 2008).

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

authority with a difficult trade-off.[3] 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. (2020), we employ Bayesian techniques featuring the Sequential Monte Carlo (SMC) sampling algorithm proposed by Herbst and Schorfheide (2014) to uncover the posterior distribution of the model's parameters over the entire parameter space.[4] This upgrade is particularly relevant given the discontinuity that arises 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 addition, 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, and Coibion and Gorodnichenko, 2011). Furthermore, trend inflation introduces a trade-off between stabilizing inflation and the output gap by adding an endogenous cost-push term into the Phillips curve (Alves, 2014). In fact, these model attributes spawn our estimated policy rule for the pre-Volcker period: it is active with respect to inflation as in Hirose et al. (2020) 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 trade-off between inflation and output gap stabilization. It can be best understood via the trade-

[3]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.

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

off's connection to real wage rigidity, a factor that has also been suggested to be important for understanding other macroeconomic puzzles.[5] Only in specifications of the estimations that yield identifications of both commodity price shocks as well as wage rigidity, do we also identify a clearly negative output gap (and thus a trade-off) for the 70s. This suggests that the estimated policy responses to inflation and the output gap are connected to an environment with inflation-output gap trade-offs: fitting the observed nominal interest rate (which is an observable in the estimation) in a more stagflationary environment requires a stronger response to inflation or a weaker response to the output gap, which is what we find. And it is this combination that is key for our determinacy result during the pre-Volcker era. Does this imply that the Federal Reserve completely overlooked the real-side of the economy in setting its policy? Most likely not, since instead of responding to the output gap (which is unobservable), our estimation suggests that the Federal Reserve responded to the output growth instead.

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. (2020). 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. 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.

[5] 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.

Finally, we explore two alterations: i) using real-time data to estimate the monetary policy rule; ii) replacing real wage rigidity by nominal wage stickiness. We document how differences in the estimates of monetary policy coefficients – and their implications for indeterminacy during the Seventies – are related to alternative econometric strategies. In particular, we compare single-equation reduced-form estimation of the monetary policy rule using real-time data and likelihood-based Bayesian estimation of a full-fledged DSGE model using *ex post* data.

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.[6] Hirose et al. (2020) 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.[7] Also, we model commodity 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 as the CBO's output gap.

Our conclusion that the pre-Volcker period is best characterized by a unique equilibrium stands in line with Orphanides (2004) and Bilbiie and Straub (2013). Orphanides (2004) uncovers an active Taylor-type rule on the basis of real-time data. Bilbiie and Straub (2013) – building on Bilbiie's (2008) inverted aggregate demand

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

[7] Arias et al. (2020) also work off a medium-scale model with trend inflation but do not estimate the indeterminate version of the model since it involves higher order indeterminacy.

logic – find evidence for both a passive monetary policy and limited asset market participation during the pre-Volcker period, thereby implying equilibrium determinacy. They further show that as the share of agents participating in asset markets has increased, the IS curve's slope flipped and policy became active which again results in equilibrium determinacy for the Great Moderation period.[8]

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. However, 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.[9]

[8] Bilbiie et al. (2008) show that asset market participation also helps explain the change in transmission of fiscal policy shocks in the United States. We keep an exploration of the implications of limited asset market participation for future research.

[9] 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.[10] 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, 1998). 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.

[10] 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.[11] 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.[12] Real wage rigidity partially undoes this effect and the minimum response 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, real 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

[11] 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 $\alpha = \chi = 0$.

[12] The figure shows that our threshold value of ψ_π for determinacy is equal to one when the annualized trend inflation rate equals 2%, while Coibion and Gorodnichenko (2011) find a higher threshold value. The difference arises from the respective use of homogenous versus firm-specific labor. We assume homogenous labor following Ascari and Sbordone (2014), who also report a threshold value close to one at 2% trend inflation rate (see Figure 11 in Ascari and Sbordone, 2014).

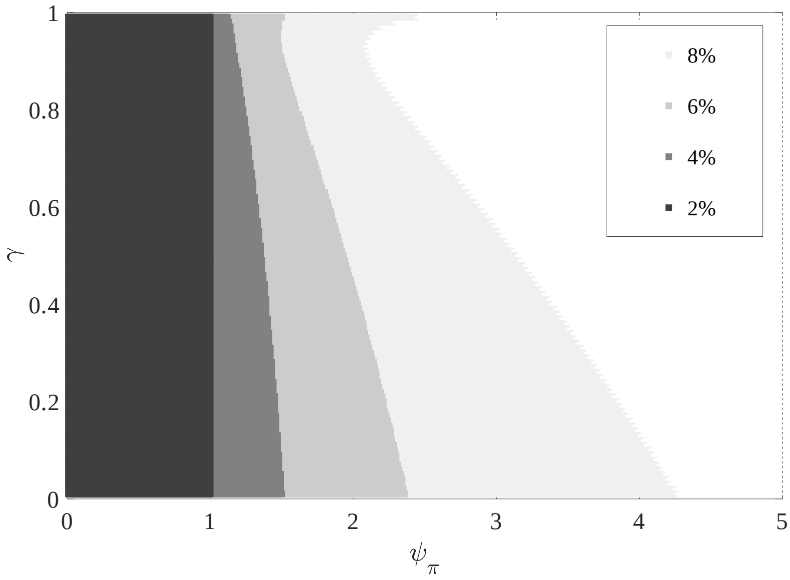

Figure 1: Indeterminacy zones (shaded)

words, with sticky real 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 otherwise it would have to in the absence of real wage rigidity.[13]

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.[14] 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

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

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

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), 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.[15] In the appendix, 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. (2020) by employing the Sequential Monte Carlo algorithm of Herbst and Schorfheide (2014) to produce an accurate approximation of the posterior distribution.[16] 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.[17] The likelihood function is given by

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

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

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

[17] 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.

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 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. (2020). 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.[18] 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.

[18] 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).[19] 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

[19] 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.[20] 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. (2020) and Nicolò (2019).

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

[20] 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).

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]

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.

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. (2020). However, our estimates of the central bank's responses to the output gap and output growth differ from Hirose et al. (2020). 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 a weak response to the output gap holds the key to our result that the US economy was likely in the determinacy region even 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. (2020). 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: 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.

Table 3 confirms that this estimation favors indeterminacy in the pre-Volcker period in line with Hirose et al. (2020).[21]

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.[22] In the third column of Table 4, we see that the posterior of γ is similar to the prior, indicating that the 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

[21] We obtain a somewhat lower probability of indeterminacy than Hirose et al. (2020). This slight difference is explained by the fact that our model features homogenous labor as in Ascari and Sbordone (2014), while Hirose et al. (2020) assume firm-specific labor. Moreover, they use a different measure of inflation (GDP deflator) to estimate their model.

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

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 in the artificial economy.

Hence, we next simultaneously treat both headline and core inflation as observables and our data set 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.

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]

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 (2020). 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 mostly 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 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.[23]

Figure 2 shows the posterior mean estimates of ψ_π and ψ_x for the pre-Volcker period in four different estimation setups.[24] 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. 2020), 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 2 imply that responding to the output gap is destabilizing. The North West panel reports results that are in line with the substantial uncertainty

[23] Hirose et al. (2020) 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.

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

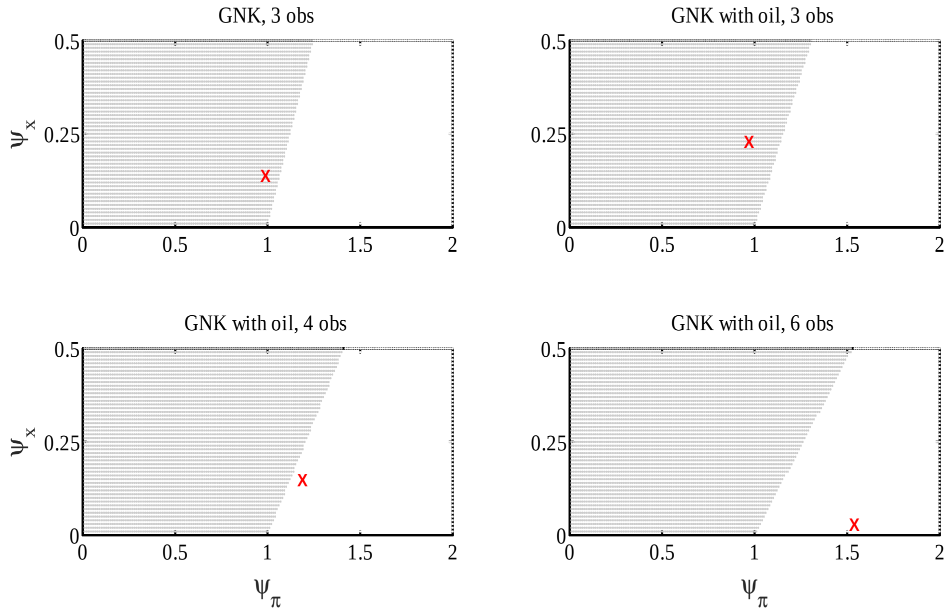

Figure 2: Indeterminacy regions in the $\psi_\pi - \psi_x$ space.

found in the literature about whether or not the Taylor principle was satisfied in the pre-Volcker era (Clarida et al., 2000, Orphanide, 2004, Lubik and Schorfheide, 2004, Coibion and Gorodnichenko, 2011, Hirose et al., 2020). 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.[25]

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 1970s. This rigidity, together with positive trend inflation, 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.

[25] 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).

4.3 Identifying cost-push shocks and the output gap

Here we address two aspects pertaining to the estimation. First, Figure 3 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 – 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 appendix, 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 4 compares our smoothed estimates of the model's output gap against the CBO output gap.[26] 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 inflation series exactly identifies commodity price shocks, this feature of our econo-

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

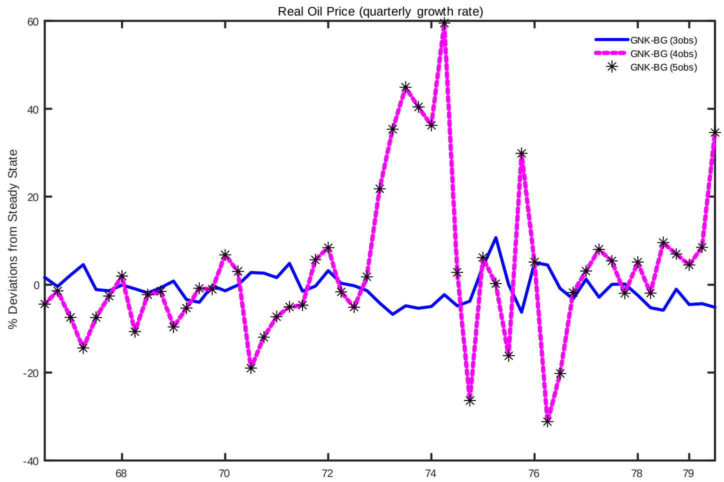

Figure 3: Identification of commodity price shocks

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

metric 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.

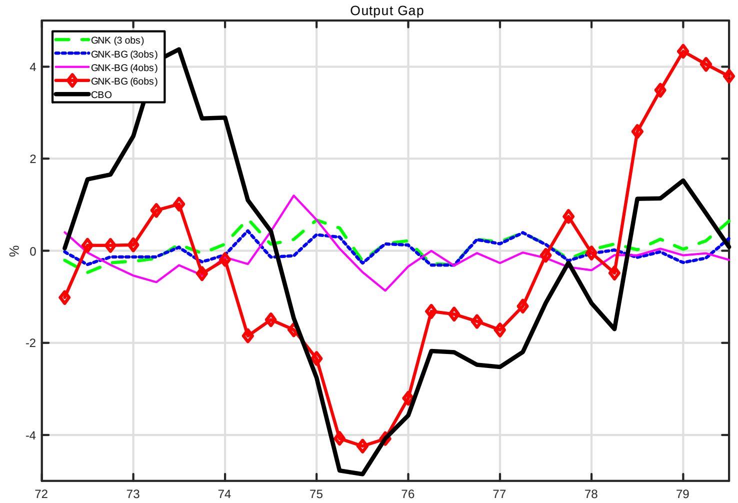

Figure 4: Output gaps *vis-à-vis* CBO.

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 5 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.[27]

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

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

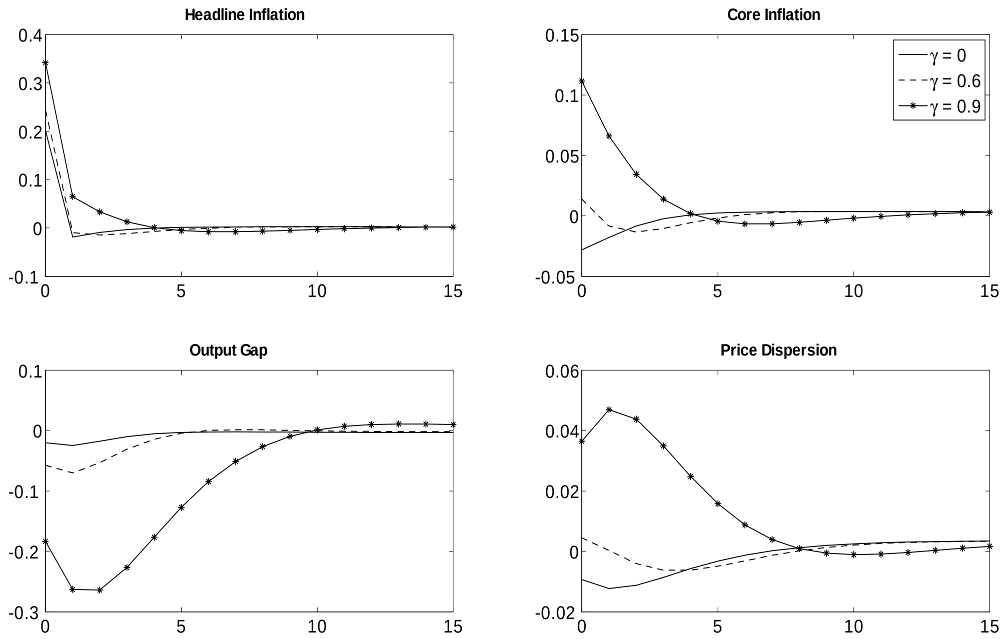

Figure 5: Model-based impulse response functions to a positive commodity price shock

lowers marginal costs (Blanchard and Galí, 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 5), 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. Moreover, the response of the output gap is now more negative, thereby confronting the central bank with a worse trade-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 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).[28] 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 Galí (2010) and Blanchard and Riggi (2013) and can be interpreted as, for instance, capturing the decline in unions bargaining power.[29] Lastly, 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

[28] 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.

[29] 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.

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%

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.[30] 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.

5.2 Labor market changes and the Great Moderation

We next inspect how changes in business cycle dynamics are related to key labor market variables along the lines of Champagne and Kurmann (2013). Table 7 reports the standard deviations and correlations of HP-filtered GDP (real per capita), hours worked (non-farm business sector's and per capita), labor productivity (per hour of all persons) and real wages (hourly compensation, NHC, deflated by the CPI).[31] For

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

[31] The table reports only data on hourly compensation in the NFB sector to be comparable with Champagne and Kurmann (2013), unlike in our model estimation where we had included two wage series reflecting on well-known difficulties in measuring aggregate wages (Justiniano et al., 2013). We have also bandpass filtered and the results remain qualitatively unchanged.

Table 7: Changes in Labor Market Dynamics

	Data			Model		
	pre-79	post-84	Relative	pre-79	post-84	Relative
$\sigma(y)$	1.85	0.94	-97%	1.82	0.94	-94%
$\sigma(n)/\sigma(y)$	1.09	1.48	+36%	0.88	0.86	-2%
$\sigma(w)/\sigma(y)$	0.57	1.22	+114%	0.57	1.00	+75%
$\sigma(y/n)/\sigma(y)$	0.69	0.86	+25%	0.42	0.59	+41%
$\rho(y,w)$	0.65	0.06	-0.59	0.02	0.26	+0.24
$\rho(y,y/n)$	0.61	0.09	-0.52	0.49	0.52	+0.03
$\rho(n,y/n)$	0.15	-0.49	-0.64	0.10	-0.07	-0.17

Notes: The column 'Relative' reports the percentage change for the standard deviations or the difference between the correlations.

the pre-1979 period, the model matches all volatilities fairly closely as well as most correlations including Christiano and Eichenbaum's (1992) hours-productivity puzzle. The model further predicts the observed decline of output volatility as well as the increases of the relative volatilities of productivity and hourly wages during the Great Moderation. Champagne and Kurmann (2013) coin this upsurge the *great increase in relative wage volatility.* In relation to our paper, Champagne and Kurmann (2013) show that changes in the systematic component of monetary policy can only have modest effects on relative wage volatility. Hence, they suggest that other kinds of changes, to factors that directly affect firms' labor demand and the nature of wage setting, offer more plausible explanations of the observed rise in relative wage volatility. Along these lines, from the viewpoint of our model, the decline in the estimated degree of real wage rigidity across the two periods does contribute to increasing relative wage volatility while simultaneously reducing business cycle fluctuations. In other words, consistent with Champagne and Kurmann (2013), our findings confirm that a decline in real wage rigidity provides a contender for the great increase in relative wage volatility.[32]

Table 7 shows that model wages appear to be roughly acyclical in both periods whereas data suggests moderately procyclical wages for pre-1979. The model also performs less successfully in regards to the vanishing cyclicality of labor productivity. The acyclical pattern of wages is related to our wage specification: with the estimated

[32] We admittedly model the change in real wage rigidity in an *ad hoc* fashion, while Champagne and Kurmann (2013) offer a more structural account of the decline in real wage rigidity.

high degree of rigidity in the pre-Volcker period, wages are largely backward looking disconnected from the marginal rate of substitution. Wage cyclicality in the model increases slightly during the Great Moderation which suggests that shocks affecting the labor demand curve have become relatively more important. This finding is qualitatively similar to Champagne and Kurmann (2013), who also report a counterfactual increase in wage cyclicality along with an unchanged cyclicality of labor productivity. They suggest that additional frictions that affect the marginal rate of substitution would decrease the cyclicality of wages. We leave this interesting avenue for future research.

5.3 Counterfactuals

To put the Federal Reserve's actions during the 1970s in perspective, we next 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, ρ_R, τ, π^* and σ_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 8 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 Galì (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. Of course, this finding also parallels Champagne and Kurmann (2013). Finally, favorable 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. [33]

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 unblemished: 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.

5.4 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) and Bjørnland et al. (2018).[34] Since the late 1990s, the global economy

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

[34]Nakov and Pescatori (2010) treat the real price of oil as observable and find that oil price shocks became 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 appendix, we use oil price data in the estimation and find a decline in the standard deviation of oil price shocks.

Table 8: 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%

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 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).[35] Figure 6 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

[35]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.

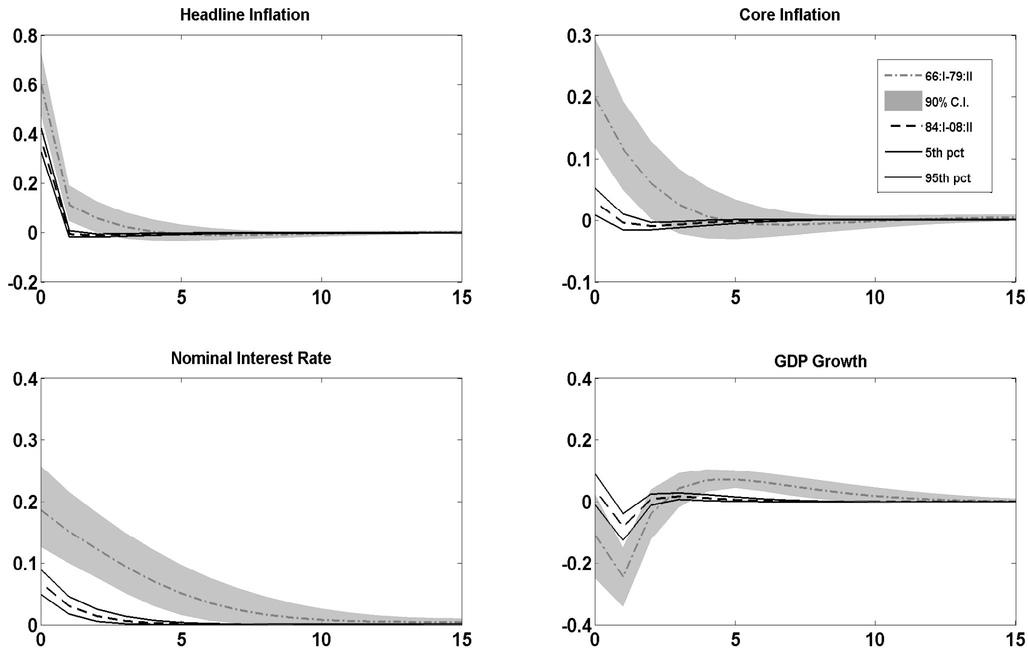

Figure 6: Bayesian impulse response functions to a positive commodity price shock

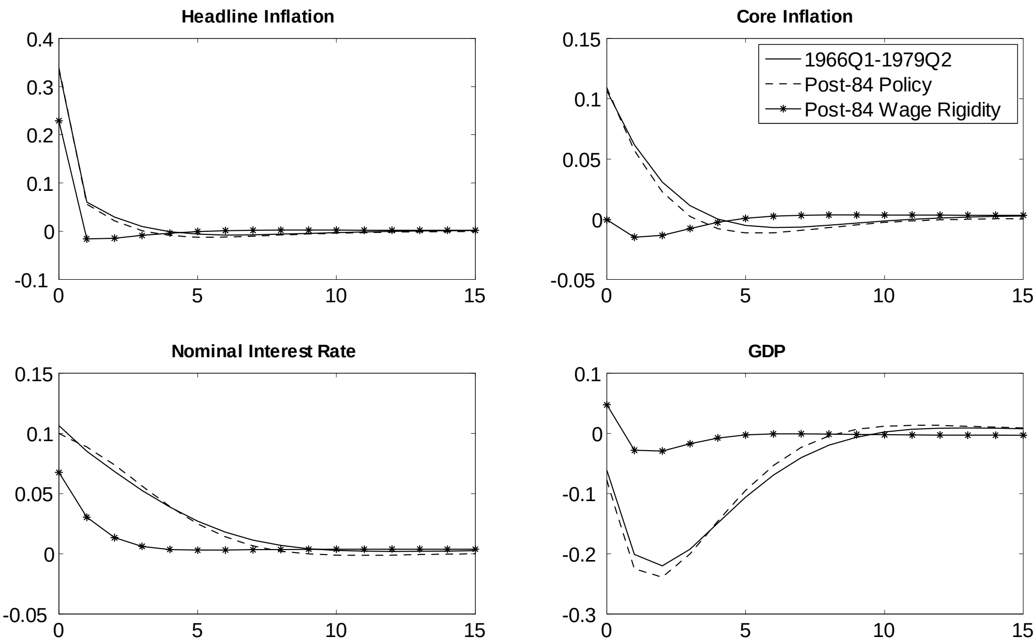

Figure 7: Counterfactual impulse response functions to a commodity price shock

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 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 7 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 Real time data and nominal wage rigidity

Through the lens of our artificial economy, U.S. monetary policy did not generate indeterminacy in the 1970s. Naturally, our interpretation hinges on the systematic component of interest rate policy as well as on the frictions we include in our model. Regarding the interest-rate rule, we have seen that a key element in our narrative is the lack of a strong response to the output gap. In that respect, an influential strand of the literature has stressed the uncertainty that plagues real-time estimates of the output gap and how the output gap has historically been subject to large revisions (Orphanides, 2002; Orphanides and Williams, 2006). In doing so, these authors have spotlighted the sensitivity of Taylor-rule characterizations with respect to data revisions and have stressed the need to consider real-time data in order to obtain a more accurate depiction of the central bank's interest rate rule. In this section, we will explore this avenue.

In addition, we have discussed earlier how real wage rigidities in the model contribute to our determinacy result in various ways. First, real wage rigidities amplify the propagation of cost-push shocks and generate an economically meaningful trade-off between inflation and output-gap stabilization, thereby influencing the coefficient estimates of the monetary policy rule. Second, real wage rigidities raise the prospect of determinacy by making firms less forward-looking (see Figure 1). However, it is fair to recognize the *ad hoc* nature of our modelling approach. Thus, in addition to considering real-time data, we will also investigate the consequences of replacing *ad hoc* real wage rigidities by standard micro-founded nominal wage stickiness. This exercise is pertinent for at least two reasons. First, like real wage rigidities, sticky nominal wages create a trade-off for the central bank (Erceg et al. 2000) while being less 'reduced-form' in nature. Second, as opposed to real wage rigidities, nominal wage stickiness reduces the prospect of determinacy (Khan et al. 2019).[36]

6.1 Real time data

To draw a faithful portrait of the Federal Reserve's systematic behavior, Orphanides (2002) and Orphanides and Williams (2006) advocate taking into account the information available in real time to policymakers. This insight motivated Coibion and Gorodnichenko (2011) to estimate a monetary policy rule using real time data and feed their estimates into a calibrated canonical GNK model for assessing determinacy. Here, we emulate Coibion and Gorodnichenko's (2011) exercise by taking their real-time estimates of the coefficients of their mixed interest-rate rule

$$\widehat{R}_t = \rho_{R_1}\widehat{R}_{t-1} + \rho_{R_2}\widehat{R}_{t-2} + (1-\rho_R)\left(\psi_\pi E_t\widehat{\pi}_{y,t+1} + \psi_x\left(\widehat{y}_t - \widehat{y}_t^*\right) + \psi_g\widehat{g}_{y,t}\right) + \epsilon_{R,t}.$$

according to which the central bank gradually adjusts the policy rate in response to expected inflation, the current output gap and the current growth rate of output. The persistence of monetary policy is captured by the two lags of the policy rate. We focus on this specification for comparability with the recent literature, namely Ascari et al (2011), Coibion and Gorodnichenko (2011, 2012) and Arias et al. (2020).

For each sample period, we compute the probability of determinacy, based on 2000 draws from the distribution of the estimated parameters, by feeding those draws into our GNK model and calculating the share of draws yielding determinacy at six percent

[36] We offer more robustness checks in Section A.3 of the Appendix.

Table 9: Probability of Determinacy - Real Time Data

	Real wage rigidity		Nominal wage rigidity	
	pre-1979 6%	post-1984 3%	pre-1979 6%	post-1984 3%
Fraction of det. draws	0.34	1.0	0.0	0.99

(pre-1979) and three percent (post-1984) trend inflation rates. We set the remaining parameters at their posterior mean (Table 1). Table 9 presents the results in columns denoted "Real wage rigidity". For the pre-Volcker period, a third of the draws imply determinacy. This figure is substantially lower than our baseline estimate of the posterior probability of determinacy for the Seventies and would call for overturning our determinacy verdict. However, in light of Arias et al.'s (2020) results, this discrepancy is not surprising and can, to a large extent, be attributed to the different methodologies employed - model-free real-time based estimates of an interest-rate rule versus full-information likelihood-based Bayesian estimation of a full-fledged DSGE model - as we document below. At this stage, perhaps more intriguing is the following question: Why is our real-time based probability of determinacy for the Seventies not much closer to zero as reported by Coibion and Gorodnichenko (2011) and Arias et al. (2020)? We believe that the difference reflects distinct labor markets and forms of wage rigidity. In particular, while real wage rigidity increases the prospect of determinacy, nominal wage stickiness as in Arias et al. (2020) exacerbates the effects of trend inflation and raises the prospect of indeterminacy (Khan et al., 2019). This leads us to next reconsider the role of wage stickiness.[37]

6.2 A model with nominal wage rigidity

We now replace real wage rigidity by nominal wage frictions in our artificial economy. Nominal wage stickiness is routinely incorporated in DSGE models, and like real wage rigidities, introduces a trade-off for monetary policy between inflation and output gap stabilization. Assume a continuum of infinitely lived households indexed by j

[37] Coibion and Gorodnichenko's (2011) calibrated small-scale GNK (with perfectly flexible nominal wages) features firm-specific labor (instead of homogeneous labor), a characteristic which increases the prospect of indeterminacy as shown by Kurozumi and Van Zandweghe (2017). See also Haque (2019) for a related discussion.

populates the economy. Households supply labor to a monopolistically competitive market at nominal wage W_{jt} while facing a downward-sloping demand curve for their particular type of labor. At any given time, a fraction $1-\nu_w$ of households are able to change wages. Labor packers hire individual supplies N_{jt} to produce final labor services according to

$$N_t = \left(\int_0^1 N_{jt}^{\frac{\eta_w - 1}{\eta_w}} dj \right)^{\frac{\eta_w}{\eta_w - 1}}$$

where η_w is the elasticity of substitution between labor types, set at six to obtain a 20 percent wage-markup in the steady state (Khan et al., 2019).[38] Cost minimization by labor packers implies downward-sloping labor demand schedules

$$N_{jt} = \left(\frac{W_{jt}}{W_t} \right)^{-\eta_w} N_t$$

where W_t is the aggregate wage index

$$W_t \equiv \left(\int_0^1 W_{jt}^{1-\eta_w} dj \right)^{\frac{1}{1-\eta_w}}.$$

Each household maximizes utility

$$E_t \sum_{s=0}^{\infty} \beta^s d_{t+s} \left[\ln\left(C_{jt+s} - hC_{t+s-1}\right) - \psi_N \nu_{t+s} \frac{N_{jt+s}^{1+\varphi}}{1+\varphi} \right].$$

We calibrate the Frisch elasticity to one. The parameter ψ_N scales hours worked at one-third in the zero-inflation steady state. Utility flows are subject to preference shocks d_t and labor supply shocks ν_t. Accordingly, the household chooses the wage W_{jt}^* to maximize the present value of earnings net of the disutility costs associated with labor

$$\max_{W_{jt}^*} E_t \sum_{s=0}^{\infty} (\beta \nu_w)^s \left(\Xi_{jt+s} \prod_{l=1}^{s} \pi_{c,t+l-1}^{\iota_w} W_{jt}^* N_{jt+s} - d_{t+s} \psi_N \nu_{t+s} \frac{N_{jt+s}^{1+\varphi}}{1+\varphi} \right)$$

subject to

$$N_{jt+s} = \left(\prod_{l=1}^{s} \pi_{c,t+l-1}^{\iota_w} \frac{W_{jt}^*}{W_{t+s}} \right)^{-\eta_w} N_{t+s}$$

where Ξ_{jt+s} denotes the marginal value of a dollar to household j, and $\iota_w \in (0,1)$ governs the degree of indexation of nominal wages to past headline inflation.[39]

[38] We also set the price markup in steady state at 20 per cent in line with Rotemberg and Woodford (1997).

[39] We continue to abstract from indexation of non-reoptimized prices, in line with Cogley and Sbordone's (2008) reported lack of intrinsic intertia in the GNK price Phillips curve.

6.3 Determinacy, trend inflation and nominal wage rigidity

Having laid out the structure of nominal wage rigidity, we now put this alternative setup to use. We proceed in three steps. First, we pursue our investigation of real-time estimates of monetary policy, this time within the context of our GNK model with sticky nominal wages. This enables us to relate our findings more directly to Arias et al. (2020). For this exercise, we keep using Coibion and Gorodnichenko's (2011) distributions of real-time estimates of the mixed interest-rate rule, and we compute the probability of determinacy (defined as the fraction of determinate draws) for each period. Second, we return to our original full-system Bayesian approach to estimate the model with nominal wage stickiness using the same *ex post* data as in our baseline. This task allows us to assess the robustness of our determinacy verdict for the Seventies with respect to an alternative wage setting mechanism with better micro-foundations. Finally we discuss the differences between the two competing econometric strategies to test for indeterminacy: the single-equation real-time approach versus the full-system Bayesian estimation with *ex post* data.

Coibion and Gorodnichenko's (2011) approach based on real time data: Let us begin by feeding Coibion and Gorodnichenko's (2011) real-time estimates of the above mixed rule into the model with nominal wage stickiness and recompute the fraction of determinate draws for each period. To perform this task, we set the non-policy structural parameters at their posterior mean from the Bayesian estimation reported in Table 10 (more on this below). As we see in Table 9, the probability of determinacy for the pre-1979 period is now zero, instead of one third under real wage rigidities. For the post-1984 episode, conditional on three percent trend inflation, the probability of determinacy is almost one hundred percent. Hence, as we expected, replacing *ad hoc* real wage rigidities with micro-founded sticky nominal wages brings our real-time based results in line with Coibion and Gorodnichenko (2011) and Arias et al. (2020).[40]

[40] Khan et al. (2019) perform a similar exercise and find that a larger minimum response to inflation is required to ensure determinacy in the Great Moderation period. They directly feed in Coibion and Gorodnichenko's (2011) estimate for ψ_x. However, Coibion and Gorodnichenko (2011) indicate (see their footnote 20) that this parameter estimate should be divided by four beforehand.

Lubik and Schorfheide's (2004) approach based on *ex post* data: However, Lubik and Schorfheide (2004) argue that indeterminacy is a property of a system and will therefore be detected more reliably by estimating the whole model. The artificial economy now features two novel effects on the occurrence of indeterminacy coming from the labor market. On one hand, nominal wage stickiness exacerbates the effect of trend inflation and raises the prospect of indeterminacy. On the other hand, wage indexation works in the opposite direction, reducing the prospect of indeterminacy (Khan et al., 2019, and Ascari et al., 2011).[41] Hence we turn back to our original econometric strategy and estimate the GNK model with cost-push shocks and sticky nominal wages using Bayesian estimation techniques, which allow for indeterminacy, presented in section 3. For comparability, we assume that the central bank follows a version of Coibion and Gorodnichenko's (2011) mixed interest-rate rule, which responds to expected inflation, the current output gap and current output growth.[42] We set the priors to ensure a 50 per cent prior predictive probability of determinacy and use the same set of *ex post* data as in our baseline analysis in section 3.4.

Table 10 displays priors and posteriors. Most importantly, we continue to find strong support for determinacy in the Seventies. The pre-Volcker posterior probability of determinacy is now 93 percent (instead of one hundred percent under real wage rigidities). Moreover, the posterior estimates of the policy rule's coefficients for the pre-Volcker period remain similar to the values we have obtained under real wage rigidity, with a weak response to the output gap ($\psi_x = 0.07$) and strong responses to both (expected) inflation ($\psi_\pi = 1.45$) and output growth ($\psi_g = 0.25$). For the post-1984 period, the probability of determinacy is now 99 percent and the posterior mean responses to inflation ψ_π, the output gap ψ_x and output growth ψ_g are respectively 2.03, 0.11 and 0.68.

Overall, the estimates of wage and price stickiness in both periods are in the ballpark of Smets and Wouters (2007) and Justiniano et al. (2010). We further document a decline over time in the degree of wage indexation: our posterior mean estimate of wage indexation is equal to 0.47 for the pre-Volcker era and falls to 0.23 for

[41] See Figure A1 in the appendix.

[42] We calibrate the second lag of interest rate smoothing to zero to avoid a superinertial rule which would imply determinacy for any positive response to inflation.

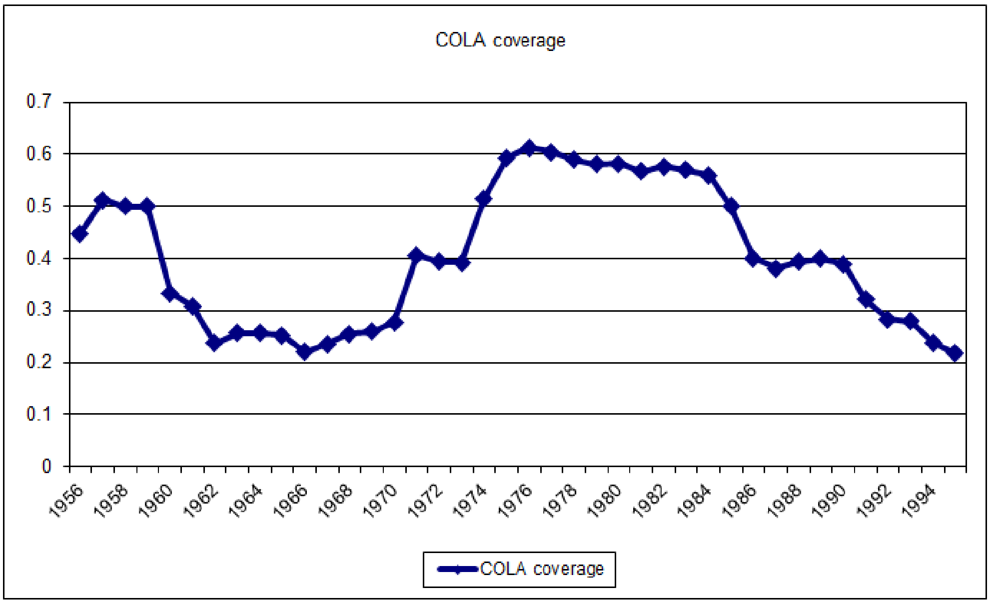

Figure 8: COLA coverage

the post-84 period. This pattern is consistent with Smets and Wouters (2007), Ascari et al. (2011) as well as Hofmann et al. (2012) who show evidence of a substantial degree of wage indexation during the Great Inflation period. It is also in line with some micro evidence for the U.S. provided by Ragan and Bratsberg (2000) who collect the cost-of-living-adjustment (COLA) coverage in individual labor contracts across 32 industries over twenty years. Figure 8 shows that COLA coverage peaked in 1976 at 61 percent of workers covered by major collective bargaining contracts, before dropping in the 1980s.[43]

Comparing the two approaches Using our GNK model with sticky nominal wages, we have employed two alternative econometric strategies to re-evaluate the concern of indeterminacy during the Seventies: i) a two-step procedure which begins with a reduced-form estimation of a policy rule using real-time data and evaluated within a calibrated DSGE model versus ii) a likelihood-based estimation of the complete DSGE model using *ex post* data. These two approaches arrive at opposite con-

[43] Special thanks to Efrem Castelnuovo for sharing this data. The COLA indicator is the fraction of unionized workers with contracts featuring a cost-of-living adjustment clause. Holland (1988) shows that COLA is a good proxy for both explicit and implicit wage indexation in the entire U.S. economy.

Table 10: Priors and Posteriors for GNK Model with Sticky Nominal Wages

Name	Density	Prior Mean (std. dev.)	Posterior Mean (Pre-79) [90% interval]	Posterior Mean (Post-84) [90% interval]
ψ_π	Gamma	1.20 (0.50)	1.45 [1.15,1.80]	2.03 [1.65,2.39]
ψ_x	Gamma	0.125 (0.10)	0.07 [0.01,0.14]	0.11 [0.01,0.19]
ψ_g	Gamma	0.125 (0.10)	0.25 [0.01,0.41]	0.68 [0.45,0.89]
ρ_R	Beta	0.50 (0.20)	0.72 [0.63,0.79]	0.76 [0.71,0.81]
π^*	Normal	1.00 (0.50)	1.20 [0.99,1.47]	0.89 [0.74,1.03]
R^*	Gamma	1.50 (0.25)	1.51 [1.26,1.77]	1.40 [1.16,1.65]
g^*	Normal	0.50 (0.10)	0.53 [0.39,0.65]	0.14 [0.03,0.24]
ξ	Beta	0.50 (0.10)	0.51 [0.41,0.62]	0.77 [0.73,0.82]
ν_w	Beta	0.50 (0.10)	0.72 [0.65,0.76]	0.70 [0.62,0.78]
ι_w	Beta	0.50 (0.10)	0.47 [0.38,0.59]	0.23 [0.13,0.32]
h	Beta	0.50 (0.10)	0.48 [0.37,0.59]	0.45 [0.33,0.56]
ρ_d	Beta	0.70 (0.10)	0.70 [0.59,0.80]	0.85 [0.78,0.92]
ρ_ν	Beta	0.70 (0.10)	0.70 [0.54,0.87]	0.98 [0.97,0.99]
σ_s	Inv-Gamma	12.00 (8.00)	17.10 [14.46,19.73]	20.56 [18.00,23.12]
σ_g	Inv-Gamma	0.50 (0.20)	0.74 [0.58,0.90]	0.83 [0.67,1.01]
σ_r	Inv-Gamma	0.50 (0.20)	0.28 [0.23,0.34]	0.16 [0.13,0.18]
σ_d	Inv-Gamma	0.50 (0.20)	2.23 [1.61,2.82]	1.67 [1.19,2.19]
σ_ν	Inv-Gamma	0.50 (0.20)	0.56 [0.18,0.93]	3.08 [2.31,3.80]
σ_ζ	Inv-Gamma	0.50 (0.20)	0.50 [0.20,0.78]	0.51 [0.21,0.84]
$M_{s,\zeta}$	Normal	0.00 (1.00)	0.09 [−1.45,1.58]	0.01 [−1.72,1.63]
$M_{g,\zeta}$	Normal	0.00 (1.00)	0.11 [−1.56,1.69]	−0.11 [−1.82,1.57]
$M_{r,\zeta}$	Normal	0.00 (1.00)	−0.02 [−1.55,1.57]	0.13 [−1.49,1.97]
$M_{d,\zeta}$	Normal	0.00 (1.00)	0.22 [−1.44,1.74]	0.10 [−1.60,1.78]
$M_{\nu,\zeta}$	Normal	0.00 (1.00)	0.03 [−1.53,1.65]	−0.52 [−2.35,1.18]
λ	Normal	1.00 (0.50)	1.17 [0.94,1.40]	0.84 [0.74,0.95]
σ^2_{NHC}	Inv-Gamma	0.10 (0.20)	0.49 [0.41,0.58]	0.72 [0.63,0.80]
σ^2_{HE}	Inv-Gamma	0.10 (0.20)	0.44 [0.36,0.52]	0.13 [0.10,0.16]

clusions regarding the prospect of equilibrium determinacy for the pre-Volcker period. However, since our implementation of Coibion and Gorodnichenko (2011) was conditioned on the posterior mean estimates of the non-policy parameters obtained in the Bayesian estimation, the contrasting answers provided by the two approaches appear to stem from the differences in the parameter estimates of the interest-rate rule. In other words, the two methodologies return antipodal characterizations of the systematic part of monetary policy. To visualize this point, Figure 9 compares Coibion and Gorodnichenko's (2011) distributions of policy parameter estimates (dashed lines) and the posterior distributions from our Bayesian estimation (solid lines). The DSGE-based density of ψ_π unequivocally supports the view that the Federal Reserve has set an active rule during the Seventies. The distribution is narrowly concentrated around 1.4 and assigns negligible weight to values less than one. Instead, Coibion and Gorodnichenko's (2011) distribution of ψ_π is more diffuse, centred around 1 and assigns considerable mass to values below one. The estimates of the response to the output gap ψ_x also differ significantly across the two methods: the DSGE-based density peaks at 0.05, while Coibion and Gorodnichenko's (2011) distribution favors values in the interval $[0.1, 0.2]$. Khan et al. (2019) and Arias et al. (2020) show that a positive response to the output gap is highly destabilizing in GNK models with nominal wage stickiness. Finally, the DSGE's distributions point to a stronger response to output growth and a higher degree of interest rate smoothing, both of which foster determinacy. Thus, each discrepancy in the distributions of policy parameters across the two methods contributes to explaining the higher DSGE-based probability of determinacy.

Given the influence of ψ_π and ψ_x on the danger of indeterminacy, it is natural to ask the following question: why do our estimates of ψ_π and ψ_x differ from the ones in Coibion and Gorodnichenko (2011)? When estimating their mixed interest-rate rule, Coibion and Gorodnichenko (2011) treat both expected inflation and the output gap as observables. They measure these two variables with the respective real-time estimate from the *Greenbook*. In contrast, the output gap and expected inflation are latent variables in our Bayesian estimation. Hence, as a external validation check of our full-system likelihood-based approach, we inspect how our DSGE-based estimates

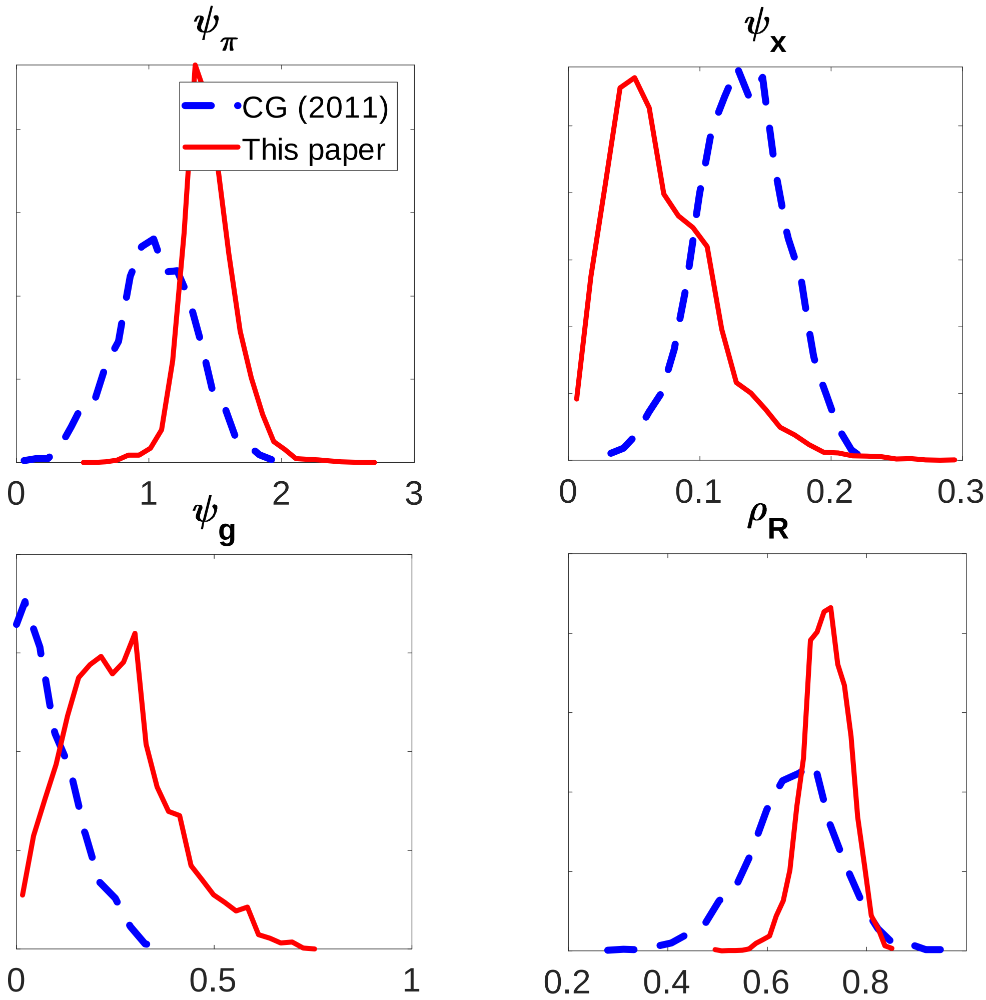

Figure 9: Distributions of monetary policy coefficients for the pre-79 period. Solid lines are the posterior distributions from the GNK model with cost-push shocks and nominal wage stickiness. Dashed lines are the distributions estimated by Coibion and Gorodnichenko (2011) using real-time data.

of expected inflation and the output gap compare to their data equivalents. This is done in Figure 10. The external validation exercise is successful for expected inflation as the real time data and smoothed series are almost identical. This is not the case for the output gap. The DSGE's output gap shares more similarity with the *ex post* CBO series than with the real time measure. The latter exhibits a pronounced downward trend throughout the Seventies which neither the CBO's nor the DSGE's output gap displays.[44] This difference between the *Greenbook* and CBO series has been documented before and reflects the Federal Reserve's difficulty in understanding the initial stages of the productivity slowdown (Orphanides, 2004). One may wonder what the consequences would be of using Coibion and Gorodnichenko's (2011) output gap data in the estimation of the DSGE model. Arias et al. (2020) explore precisely this avenue for the Great Moderation episode. They estimate a medium-scale GNK model under determinacy for the period 1984-2008 with Bayesian techniques and investigate the effects of using real time output gap data as an additional observable. They report that the estimated response to the output gap does not change much and infer that the choice of the estimation technique may matter more than the use of real-time output gap data as an observable for the parameter estimates of the policy rule. They also report that the estimated degree of nominal wage stickiness increases and that the fit of their model for inflation deteriorates.[45] Notwithstanding, Orphanides (2004) explores the use of real-time versus ex post data in the context of single-equation Taylor rule estimation and shows that the use of real-time output gap measure results in a stronger response to inflation. This leads him to suggest that "policymakers during the Great Inflation did not commit an error as egregious as the perverse response to inflation would suggest" [Orphanides, 2004, 154]. We leave the study of this intriguing issue for future research.

[44]The DSGE's output gap is positively correlated with both the Greenbook's and CBO's output gap at 0.45.

[45]Following their lead, we have conducted a similar exercise for the Seventies. Unfortunately, the convergence properties of the estimated parameters were not satisfactory, thus, we do not report details here.

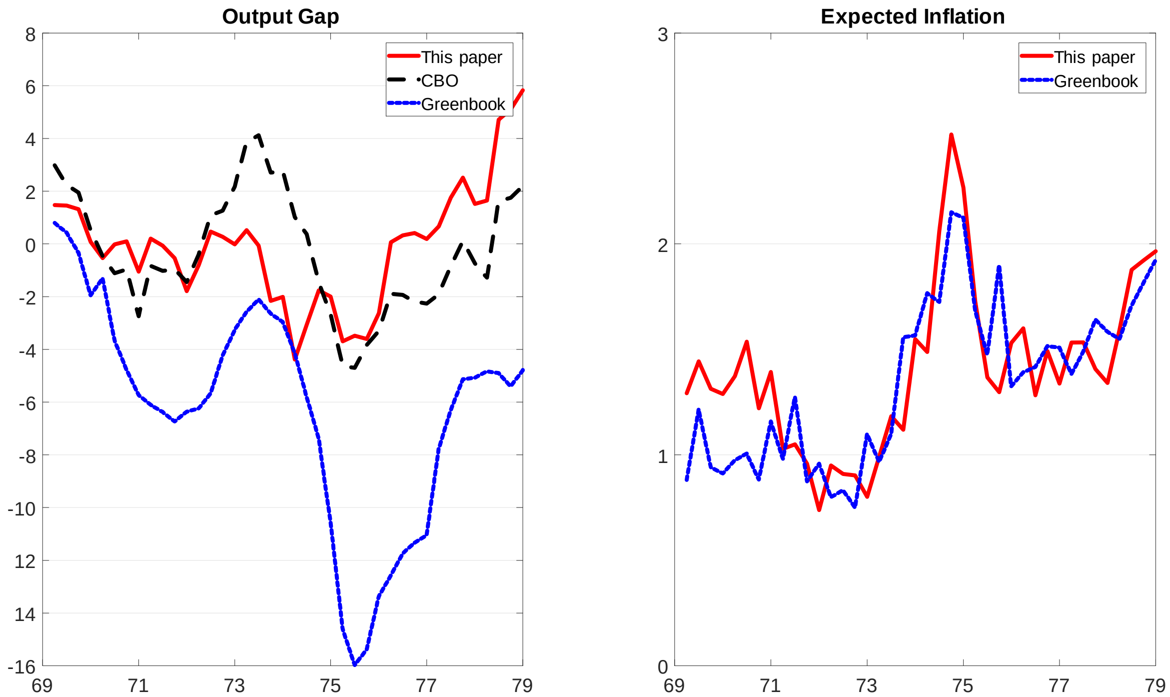

Figure 10: Comparison of smoothed estimates of output gap and expected inflation to their empirical measures.

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. (2020) employing general equilibrium estimations both suggest that the Great Inflation is best understood as the result of equilibrium indeterminacy.

The current paper advances an alternative hypothesis in an estimated artificial economy that 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. To capture this trade-off, and also to ensure that the parameter estimates of the monetary policy rule account for the endogeneity of its targeted variables, it is crucial to adopt a system-based approach in the estimation. Our econometric strategy critically disciplines the identification of cost-push shocks and finds evidence of wage sluggishness 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 negligible.

Do our findings imply that monetary policy had no destabilizing effect 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 that 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 because of the decline in real wage rigidity.

Finally, we explore two alterations: real-time estimates of the monetary policy rule and replacing real wage rigidity by nominal wage stickiness. We learn two lessons from these exercises. First, our punchline that *"The Fed did not generate indeterminacy during the Seventies"* is robust to a different form of wage rigidity. Second, using real time estimates of the monetary policy rule affects our determinacy verdict for the Seventies. The sensitivity of our punchline is consistent with Arias et al. (2020) who show that monetary policy rules estimated with a model free approach on real time data can deliver results substantially different from those implied by monetary policy rules in fully estimated DSGE models. Taking into account (in an internally consistent way) the incomplete information set available in real time to policymakers when estimating DSGE models remains a challenge. The approach pioneered by Lubik and Matthes (2016) and recently by Lubik, Matthes and Mertens (2020) in which the central bank is learning, while private-sector agents have rational expectations and complete information, offers a promising avenue for future research to explore further this issue in the context of GNK models.

Acknowledgements

The authors particularly thank Florin Bilbiie and two anonymous referees for their comments which greatly improved the article. We are also grateful to Gianni Amisano, Guido Ascari, Drago Bergholt, Hilde Bjørnland, Michael Burda, Giovanni Caggiano, Fabio Canova, Efrem Castelnuovo, Ferre De Graeve, Chris Edmond, Yunjong Eo, Andrea Ferrero, Ippei Fujiwara, Francesco Furlanetto, Pedro Gomis-Porqueras, Punnoose Jacob, Frederic Karame, Benjamin Keen, Mariano Kulish, François Langot, Thomas Lubik, James Morley, Adrian Pagan, Luca Pensieroso, Petr Sedláček, Mathias Trabandt, Harald Uhlig, Elliott Weder and Raf Wouters for helpful discussions on various drafts of this paper. This work was supported with supercomputing resources provided by the Phoenix HPC service at The University of Adelaide. Weder acknowledges research support from the Australian Research Council, under the grant DP140102869 and would also like to thank the Bank of Finland and Keio University for their hospitality. Haque acknowledges generous support from the Australian Research Council, under the grant DP170100697, and would like to thank the University of Oxford for their hospitality. Declarations of interest: none.

References

[1] Abraham, K. and J. Haltiwanger (1995): "Real Wages and the Business Cycle", Journal of Economic Literature 33, 1215-1264.

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

[3] Arias, E., G. Ascari, N. Branzoli and E. Castelnuovo (2020): "Positive Trend Inflation and Determinacy in a Medium-Sized New-Keynesian Model", International Journal of Central Banking 16, 51-94.

[4] Araújo, E. (2009): "Real Wage Rigidity and the Taylor Principle", Economics Letters 104, 46-48.

[5] Ascari, G., P. Bonomolo and H. Lopes (2019): "Walk on the Wild Side: Temporarily Unstable Paths and Multiplicative Sunspots", American Economic Review 109, 1805-1842.

[6] Ascari, G., N. Branzoli and E. Castelnuovo (2011): "Trend inflation, wage indexation, and determinacy in the U.S.", Quaderni di Dipartimento Working Paper No. 153.

[7] 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.

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

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

[10] Bachmeier, L. and B. Keen (2017): "Modeling the Asymmetric Effects of Oil Price Shocks", mimeo.

[11] Barsky, R. and L. Kilian (2001): "Do We Really Know That Oil Caused the Great Stagflation? A Monetary Alternative", NBER Macroeconomics Annual 16, 137-183.

[12] Barsky, R. and L. Kilian (2004): "Oil and the Macroeconomy since the 1970s", Journal of Economic Perspectives 18, 115-134.

[13] Barsky, R., S. Basu and K. Lee (2015): "Whither News Shocks?", NBER Macroeconomics Annual 29, 225–264.

[14] Basu, S. and C. House (2016): "Allocative and Remitted Wages", in: J. Taylor and H. Uhlig (editors) Handbook of Macroeconomics 2, Elsevier, 297-354.

[15] Beaudry, P. and J. DiNardo (1991): "The Effect of Implicit Contracts on the Movement of Wages over the Business Cycle: Evidence from Micro Data," Journal of Political Economy 99, 665-688.

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

[17] Bernanke, B., M. Gertler and M. Watson (1997): "Systematic Monetary Policy and the Effects of Oil Price Shocks", Brookings Papers on Economic Activity 28, 91-157.

[18] Bianchi, F and G. Nicolò (2019): "A Generalized Approach to Indeterminacy in Linear Rational Expectations Models", mimeo.

[19] Bilbiie, F. O. (2008): "Limited Asset Markets Participation, Monetary Policy and (Inverted) Aggregate Demand Logic." Journal of Economic Theory 140, 162-196.

[20] Bilbiie, F.O., A. Meier and G.J. Müller (2008): "What Accounts for the Changes in US Fiscal Policy Transmission?" Journal of Money, Credit and Banking 40, 1439-1470.

[21] Bilbiie, F. O. and R. Straub (2012): "Changes in the Output Euler Equation and Asset Markets Participation." Journal of Economic Dynamics and Control 36, 1659-1672.

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

[23] Bjørnland, H., V. Larsen and J. Maih (2018): "Oil and Macroeconomic (In)stability", American Economic Journal: Macroeconomics 10, 128-151.

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

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

[26] 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.

[27] Blinder, A. (1981): "Supply-shock Stagflation: Money, Expectations and Accommodation", in: J. Flanders and A. Razin (editors) Developments in an Inflationary World, Academic Press, 61-101.

[28] Blinder, A. (1982): "The Anatomy of Double-Digit Inflation in the 1970s", in: R. Hall (editor) Inflation: Causes and Effects, University of Chicago Press, 261-282.

[29] Blinder, A. and J. Rudd (2012): "The Supply-Shock Explanation of the Great Stagflation Revisited", in: M. Bordo and A. Orphanides (editors) The Great Inflation: The Rebirth of Modern Central Banking, University of Chicago Press, 119-175.

[30] Bodenstein, M., C. Erceg and L. Guerrieri (2008): "Optimal Monetary Policy with Distinct Core and Headline Inflation Rates", Journal of Monetary Economics 55, S18-S33.

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

[32] Bruno, M. and J. Sachs (1985): Economics of Worldwide Stagflation, Harvard University Press.

[33] Champagne, J. and A. Kurmann (2013): "The Great Increase in Relative Wage Volatility in the United States", Journal of Monetary Economics 60, 166-183.

[34] Christiano, L. J. and Eichenbaum, M. (1992): "Current Real-Business-Cycle Theories and Aggregate Labor-Market Fluctuations", American Economic Review 82, 430–450.

[35] 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.

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

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

[38] Coibion, O. and Y. Gorodnichenko (2012): "Why Are Target Interest Rate Changes So Persistent?", American Economic Journal: Macroeconomics 4, 126-162.

[39] Devereux, P. (2001): "The Cyclicality of Real Wages within Employer-employee Matches", Industrial and Labor Relations Review 54, 835-850.

[40] 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.

[41] Erceg, C., D. Henderson and A. Levin (2000): "Optimal Monetary Policy with Staggered Wage and Price Contracts", Journal of Monetary Economics 46, 281-313.

[42] Farmer, R, V. Khramov and G. Nicolò (2015): "Solving and Estimating Indeterminate DSGE Models", Journal of Economic Dynamics and Control 54, 17-36.

[43] Galí, J. and L. Gambetti (2009): "On the Sources of the Great Moderation", American Economic Journal: Macroeconomics 1, 26-57.

[44] Gordon, R. (1977): "Can the Inflation of the 1970s be Explained?", Brookings Papers on Economic Activity 1, 253-277.

[45] Hall, R. (2005): "Employment Fluctuations with Equilibrium Wage Stickiness", American Economic Review 95, 50-65.

[46] Haque, Q. (2019): "Monetary Policy, Inflation Target and the Great Moderation: An Empirical Investigation", CAMA Working Papers, 2019-44.

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

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

[49] Hirose, Y. (2014): "An Estimated DSGE Model with a Deflation Steady State", mimeo.

[50] Hirose, Y., T. Kurozumi and W. Van Zandweghe (2020): "Monetary Policy and Macroeconomic Stability Revisited", Review of Economic Dynamics 37, 255-274.

[51] Hofmann, B., G. Peersman and R. Straub (2012): "Time Variation in U.S. Wage Dynamics", Journal of Monetary Economics 59, 769-783.

[52] Holland, A. (1988): "The Changing Responsivess of Wages and Price-level Shocks: Explicit and Implicit Indexation", Economic Inquiry 26, 265-279.

[53] Jeanne, O. (1998): "Generating Real Persistent Effects of Monetary Shocks: How Much Nominal Rigidity Do We Really Need?", European Economic Review 42, 1009-1032.

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

[55] Justiniano, A., G. Primiceri and A. Tambalotti (2010): "Investment Shocks and Business Cycles", Journal of Monetary Economics 57, 132-145.

[56] 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.

[57] Khan, H., L. Phaneuf and J.G. Victor (2019): "Rules-based monetary policy and the threat of indeterminacy when trend inflation is low", Journal of Monetary Economics (in press).

[58] Kilian, L. (2008): “Exogenous Oil Supply Shocks: How Big Are They and How Much Do They Matter for the U.S. Economy?”, Review of Economics and Statistics 90, 216-240.

[59] Kilian, L. (2009): “Not All Oil Price Shocks Are Alike: Disentangling Demand and Supply Shocks in the Crude Oil Market", American Economic Review 99, 1053-1069.

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

[61] Leduc, S. and K. Sill (2007): "Monetary Policy, Oil Shocks, and TFP: Accounting for the decline in US volatility", Review of Economic Dynamics 10, 595-614.

[62] Liu, J. and R. Chen (1998): "Sequential Monte Carlo Methods for Dynamic Systems", Journal of the American Statistical Association 93, 1032-1044.

[63] Lubik, T. and C. Matthes (2016): "Indeterminacy and Learning: An Analysis of Monetary Policy in the Great Inflation", Journal of Monetary Economics 82, 85-106.

[64] Lubik, T., C. Matthes and E. Mertens (2020): "Indeterminacy and Imperfect Information", Deutsche Bundesbank Discussion Paper 01/2020.

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

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

[67] Mehra, Y. and B. Sawhney (2010): "Inflation Measure, Taylor Rules, and the Greenspan-Bernanke Years", Federal Reserve Bank of Richmond Econonomic Quarterly 96, 123–151.

[68] Michaillat, P. (2012): "Do Matching Frictions Explain Unemployment? Not in Bad Times", American Economic Review 102, 1721-1750.

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

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

[71] Nicolò, G. (2018): "Monetary Policy, Expectations and Business Cycles in the U.S. Post-War Period", UCLA, mimeo.

[72] Orphanides, A. (2002): "Monetary-Policy Rules and the Great Inflation", American Economic Review 92, 115-20.

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

[74] Orphanides, A. and J. Williams (2006): "Monetary Policy with Imperfect Knowledge", Journal of the European Economic Association 4, 366-375.

[75] Primiceri, G. (2005): "Time Varying Structural Vector Autoregressions and Monetary Policy", Review of Economic Studies 72, 821-852.

[76] Riggi, M. and F. Venditti (2014): "The Time Varying Effect of Oil Price Shocks on Euro Area Exports", Journal of Economic Dynamics and Control 59, 75-94.

[77] Rotemberg, J. and M. Woodford (1997): "An Optimization-based Econometric Framework for the Evaluation of Monetary Policy". In: Rotemberg, J. and B. Bernanke (Eds), NBER Macroeconomics Annual 1997. MIT Press, Cambridge, MA, 297-346.

[78] Sims, C. and T. Zha (2006): "Were there Regime Switches in US Monetary Policy?”, American Economic Review 96, 54-81.

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

[80] Uhlig, H. (2007): "Explaining Asset Prices with External Habits and Wage Rigidities in a DSGE Model", American Economic Review Papers and Proceedings 97, 239-243.

[81] Walsh, C. (2003): "Speed Limit Policies: The Output Gap and Optimal Monetary Policy", American Economic Review 93, 265-278.

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.

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

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

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

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

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 $P_{c,t} \equiv P_{q,t} s_t^{\chi}$, 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

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

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

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

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 .

A.3 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 A1 summarizes the log-data densities and the posterior probabilities of determinacy, while the parameter estimates are reported in Tables A2 and A3.

A.3.1 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.[46] 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 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

[46] 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.

region (Ascari and Sbordone 2014; Hirose et al. 2020).[47] 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.

Table A1: 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

A.3.2 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.

[47] 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.

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 observables. 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 2). 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.

Tables A2 and A3 report the posterior means and 90 percent highest posterior density intervals of the parameters for the robustness checks.

A.4 Nominal wage rigidity and wage indexation

To illustrate the effect of wage indexation, Figure A1 plots the (in)determinacy regions of the model in the $\psi_\pi - \psi_x$ space for various levels of trend inflation. Panel (a) shows the case where there is no wage indexation, while in panel (b) we set the degree of wage indexation to its estimated posterior mean value for the pre-Volcker period.[48] As seen in panel (a), nominal wage stickiness exacerbates the implications of trend inflation for indeterminacy, as suggested by Khan et al. (2019). However, as seen in panel (b), wage indexation dampens this effect of nominal wage stickiness and trend inflation on indeterminacy as suggested by Ascari et al. (2011).

[48] The remaining parameters are set at their posterior mean values for the pre-Volcker period.

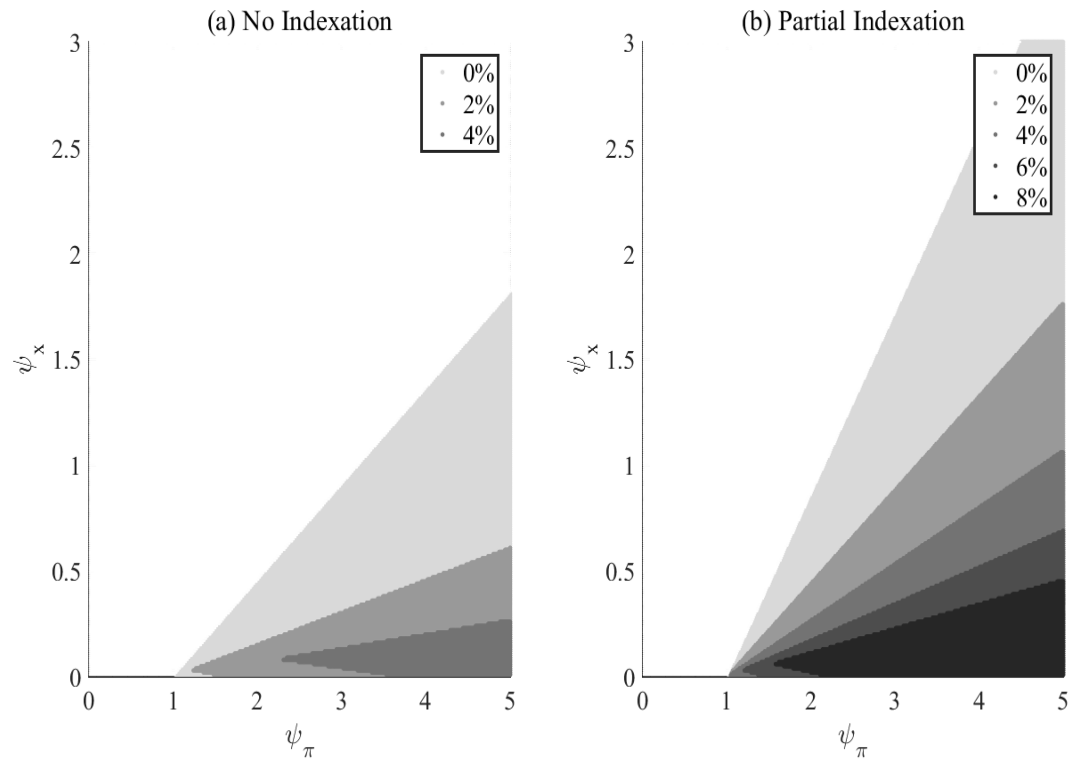

Figure A1: Determinacy regions

Table A2: 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 A3: 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]

Economics Working Papers

2019-07: Martin Paldam: Does system instability harm development? A comparative empirical study of the long run

2019-08: Marianne Simonsen, Lars Skipper, Niels Skipper and Peter Rønø Thingholm: Discontinuity in Care: Practice Closures among Primary Care Providers and Patient Health

2019-09: Leonidas Enrique de la Rosa and Nikolaj Kirkeby Niebuhr: Loss aversion and the zero-earnings discontinuity

2019-10: Emma von Essen, Marieke Huysentruyt and Topi Miettinen: Exploration in Teams and the Encouragement Effect: Theory and Evidence

2019-11: Erik Strøjer Madsen: From Local to Global Competitors on the Beer Market

2020-01: Nikolaj Kirkeby Niebuhr: Managerial Overconfidence and Self-Reported Success

2020-02: Tine L. Mundbjerg Eriksen, Amanda Gaulke, Niels Skipper and Jannet Svensson: The Impact of Childhood Health Shocks on Parental Labor Supply

2020-03: Anna Piil Damm, Helena Skyt Nielsen, Elena Mattana and Benedicte Rouland: Effects of Busing on Test Scores and the Wellbeing of Bilingual Pupils: Resources Matter

2020-04: Jesper Bagger, Francois Fontaine, Manolis Galenianos and Ija Trapeznikova: Vacancies, Employment Outcomes and Firm Growth: Evidence from Denmark

2020-05: Giovanni Pellegrino: Uncertainty and Monetary Policy in the US: A Journey into Non-Linear Territory

2020-06: Francesco Fallucchi and Daniele Nosenzo: The Coordinating Power of Social Norms

2020-07: Mette T. Damgaard: A decade of nudging: What have we learned?

2020-08: Erland Hejn Nielsen and Steen Nielsen: Preparing students for careers using business analytics and data-driven decision making

2020-09 Steen Nielsen: Management accounting and the idea of machine learning

2020-10 Qazi Haque, Nicolas Groshenny and Mark Weder: Do We Really Know that U.S. Monetary Policy was Destabilizing in the 1970s?