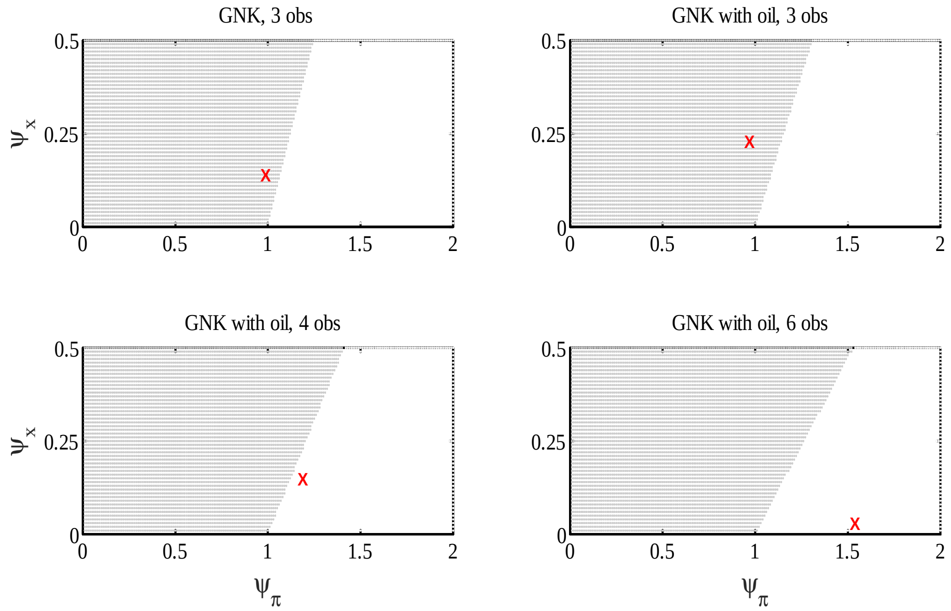

Figure 3: Indeterminacy regions in the $\psi_\pi - \psi_x$ space.

South East panel. In all cases, the parameters (other than ψ_π and ψ_x) are set at their posterior mean and crosses locate the posterior mean of the two policy parameters. Reminiscent of Ascari and Ropele (2009) and Coibion and Gorodnichenko (2011), the areas displayed in Figure 3 imply that responding to the output gap is destabilizing. The North West panel reports results that are in line with the substantial uncertainty found in the literature about whether or not the Taylor principle was satisfied in the pre-Volcker era (Clarida et al. 2000; Orphanides 2004; Lubik and Schorfheide 2004; Coibion and Gorodnichenko 2011; Hirose et al. 2017). Instead, in the South East panel which involves estimation with all six observables, the combination of a clearly active ψ_π and a virtually zero ψ_x puts the economy unambiguously into the determinacy region.[21]

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 wage data is included as an observable, a significant degree of real wage rigidity arises for the 1970s and this rigidity breaks down the divine coincidence. Together

[21] 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).

with commodity price shocks, this opens the door for a trade-off between stabilizing inflation and the output gap for which we can account for. This trade-off considerably affects the estimates of the systematic component of monetary policy. As a result, indeterminacy of the system disappears as an explanation of the Great Inflation.

4.2 A closer look at parameter estimates and the Great Moderation

Table 4 details the parameter estimates. We find that the estimated response to inflation in the Taylor rule is passive for the GNK model estimated using three observables. This result is in line with the previous literature. 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 turns active. Yet, that is not enough to completely rule out indeterminacy as the Taylor principle is not sufficient to guarantee a determinate equilibrium in a model with trend inflation. However, once we add both 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 at more than 1.5. At the same time, the Federal Reserve's response to the real economy changed: the policy parameter 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.

This result can be understood as follows. Real wage rigidity dampens the effect of trend inflation on indeterminacy as documented earlier. Given the estimated levels of rigidity and trend inflation, the minimum response to inflation required to ensure determinacy is much lower than in a model with flexible real wages (recall Figure 1). As such, a strong response to inflation is almost sufficient to guarantee determinacy. Then, the estimated weak response to the output gap pushes the economy explicitly into the determinacy region.[22]

Let us next compare the pre-Volcker and the Great Moderation periods (you can follow this in the last two columns of Table 1). The key finding is that the policy responses to inflation and output growth almost double while trend inflation falls, which aligns with Coibion and Gorodnichenko (2011). The policy response to the output gap ψ_x remains relatively weak. Also, the Federal Reserve moves its focus away from responding to headline inflation toward core inflation during the Great Moderation. This echoes Mehra and Sawhney (2010).[23] Lastly, real wage rigidity declines over time, however, unlike Blanchard and Riggi (2013), the point estimate still implies a considerable degree of rigidity. This difference of results is most likely reflected in the different estimation strategies: Blanchard and Riggi (2013) adopt a limited information approach that matches impulse responses to an oil price shock in their DSGE model and in a structural VAR while we use full-information Bayesian estimation with multiple shocks. The volatilities of both commodity price shocks and labor supply shocks increase across the two periods (as seen in Table 1). As in Bjørnland et al. (2018), this rise in the volatility of commodity price shocks could simply reflect more episodes of high oil price volatility in the post-1984 period. Innovations to the variance of monetary policy shocks and discount factor shocks decline quite considerably while the size of the technology shock remain fairly stable.

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 5 summarizes the model's implications for the volatility of inflation (both headline and core) and output growth – evaluated at its posterior mean – along with U.S. data. The estimated model replicates the observed volatility drops.[24] Despite the fact that our model is relatively small compared to models of Smets and Wouters (2007) or Justiniano and Primiceri (2008), the replication is assuring in terms of the empirical plausibility of our estimation results.

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

[23] For a related analysis see Doko Tchatoka et al. (2017).

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

Table 5: The Great Moderation

	1966:I-1979:II		1984:I-2008:II		Percent Change	
	Data	Model	Data	Model	Data	Model
Headline Inflation	0.68	1.04	0.38	0.45	-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%

4.3 Identification issues

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

Second, as the output gap takes on a central role in the model's interpretation of the economy, it is important to know if the estimated series of the output gap

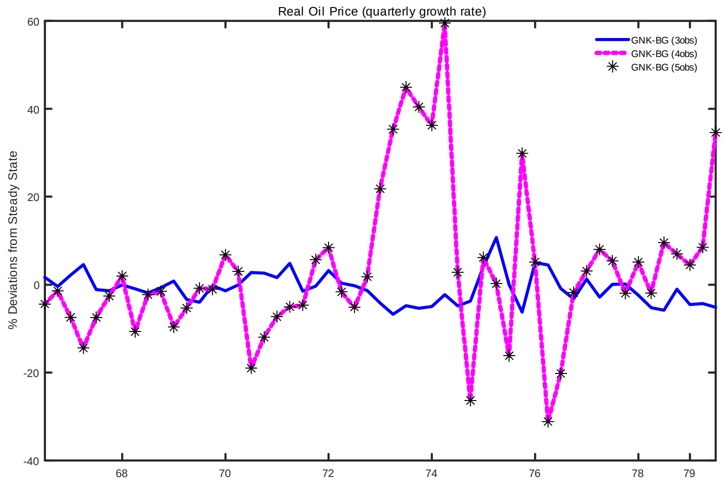

Figure 4: Identification of commodity price shocks

resembles empirical counterparts. Given that the estimation takes place in a system, it is *a priori* not necessary that the estimated series is close to an empirical proxy that is constructed using orthogonal information. Figure 5 shows that for all estimations that do not include wage data, the estimated series of the output gap is basically a flat line that has no resemblance to the Congressional Budget Office (CBO) based series. Phrased alternatively, while the use of two inflation series identify commodity price shocks, it falls short of doing the same regarding the output gap. Yet, once information on wages is included and the propagation dynamics set, the smoothed series of the output gap is highly correlated with the CBO data and, returning to Table 2, indeterminacy can then be ruled out for the Seventies.

5 The comovement between inflation and the output gap

Next, we explore how important real wage rigidity is in generating a negative relationship between inflation and economic activity. Figure 6 plots impulse response functions for headline inflation, core inflation, the output gap and price dispersion to a ten percent commodity price shock. To better sift out the role of slow wage

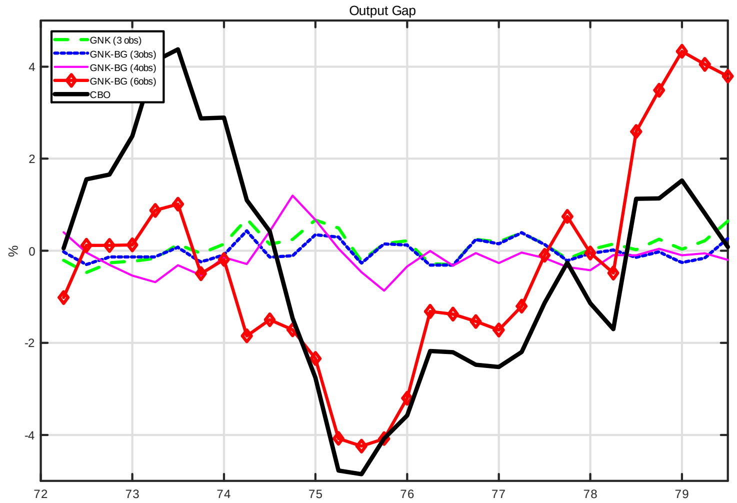

Figure 5: Output gaps *vis-à-vis* CBO.

adjustments, each plot considers three calibrations of the rigidity parameter γ.[25]

In the presence of complete real wage flexibility, $\gamma = 0$, headline inflation increases (mechanically with oil prices) while core inflation and price dispersion decrease and the output gap hardly moves at all. With flexible wages, an increase in the real price of oil reduces the real wage and consequently lowers marginal costs. As a result, both desired prices and price dispersion fall. On the other hand, for higher levels of real wage stickiness (e.g. $\gamma = 0.9$ in Figure 6), output and inflation negatively comove and policy-makers face a trade-off between output gap and inflation (both headline and core) stabilization. With real wages being rigid, an increase in the real price of oil results in an increase in the firms' marginal costs as well as desired prices and core inflation. Also, price dispersion increases which leads to further endogenous rise in inflation. Therefore, higher real wage rigidity generates a significant trade-off for the central bank following a commodity price shock. A stable output gap is thus inconsistent with either stable headline and/or core inflation.

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

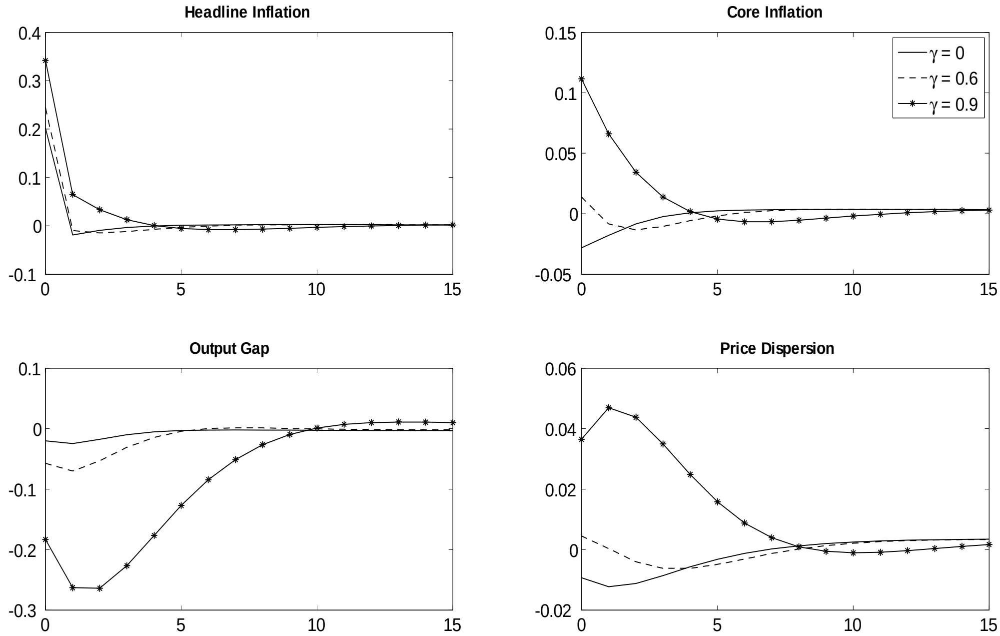

Figure 6: Model-based impulse response functions to a positive commodity price shock

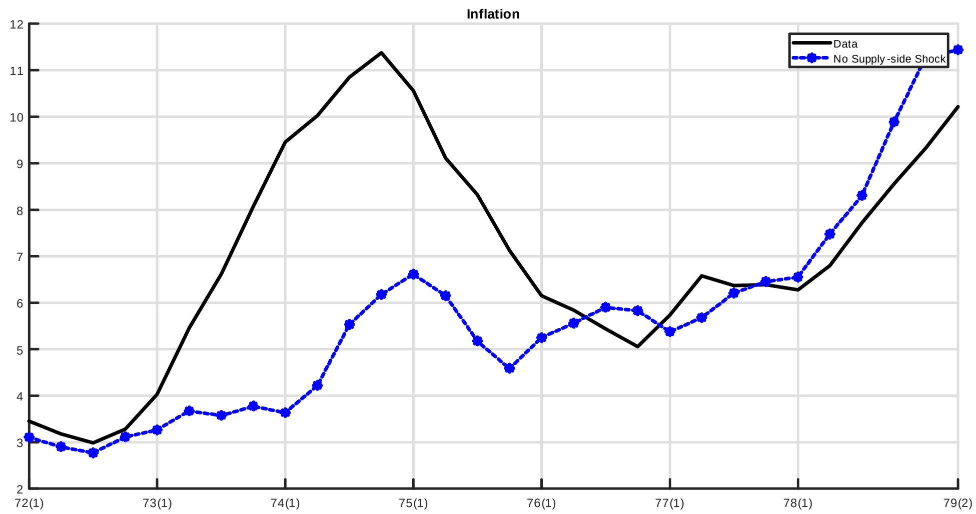

Figure 7: Counterfactual path of inflation (y-o-y) in absence of aggregate supply shocks.

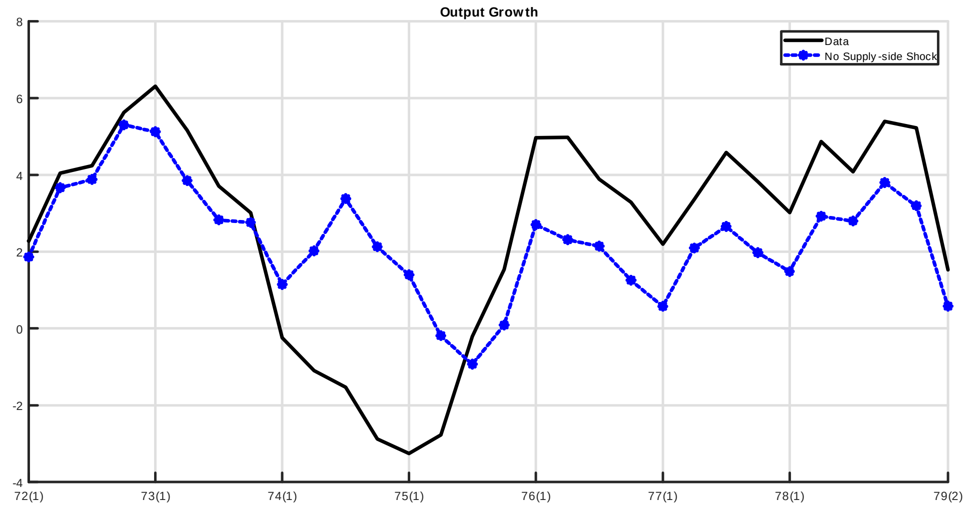

Figure 8: Counterfactual path of output growth (y-o-y) in the absence of aggregate supply shocks.

6 What caused the stagflation?

The above results suggest that monetary policy was active in the Seventies and, through the lens of our trend inflation model, indeterminacy was not the likely factor behind the high inflation rates. Rather, our estimation points to supply shocks similar to Gordon (1977) and Blinder (1982) to have caused the Great Inflation. To demonstrate this, we next undertake counterfactuals where we shut down the smoothed series of estimated supply shocks. This allows to extract the shocks' relative effects on the observed paths of inflation and output growth and in particular on their stagflationary pattern in the mid-1970s. Figures 7 and 8 plot the counterfactual paths along with actual data. Once the supply shocks are gone, the rise of inflation from 1973 to 1975 disappears to a large extent. Furthermore, the drop in output is significantly smaller. In sum, without supply shocks, the first stagflationary episode would not have taken place.

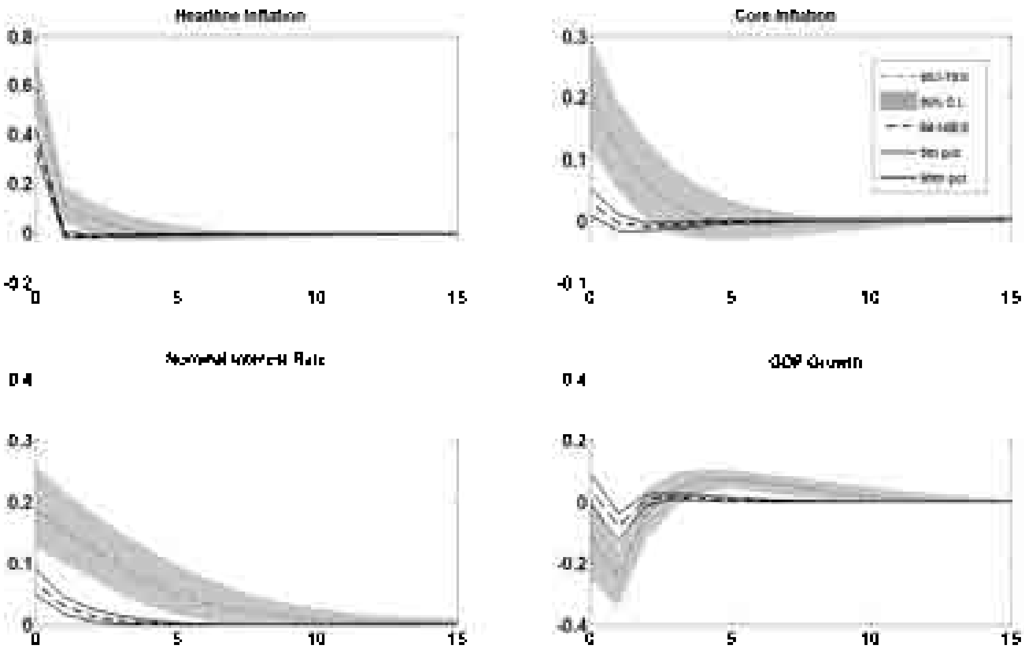

Figure 9: Bayesian impulse response functions to a positive commodity price shock

7 Changes in the propagation of commodity price shocks

This section studies how the propagation of commodity price shocks has changed over time. We begin by depicting the estimated mean impulse responses of headline inflation, core inflation, nominal interest rate and output growth for both sample periods along with the 90 percent probability intervals. Figure 9 shows that the effects of commodity price shocks have changed significantly over time: we find much smaller effects on core inflation, real activity and interest rate in the second subsample, despite the fact that the 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, these findings are reassuring as they match the empirical VAR evidence put forth by Blanchard and Galí (2010), Blanchard and Riggi (2013) and in particular Kilian (2008, 2009) as well as Barsky and Kilian (2001, 2004) and others.

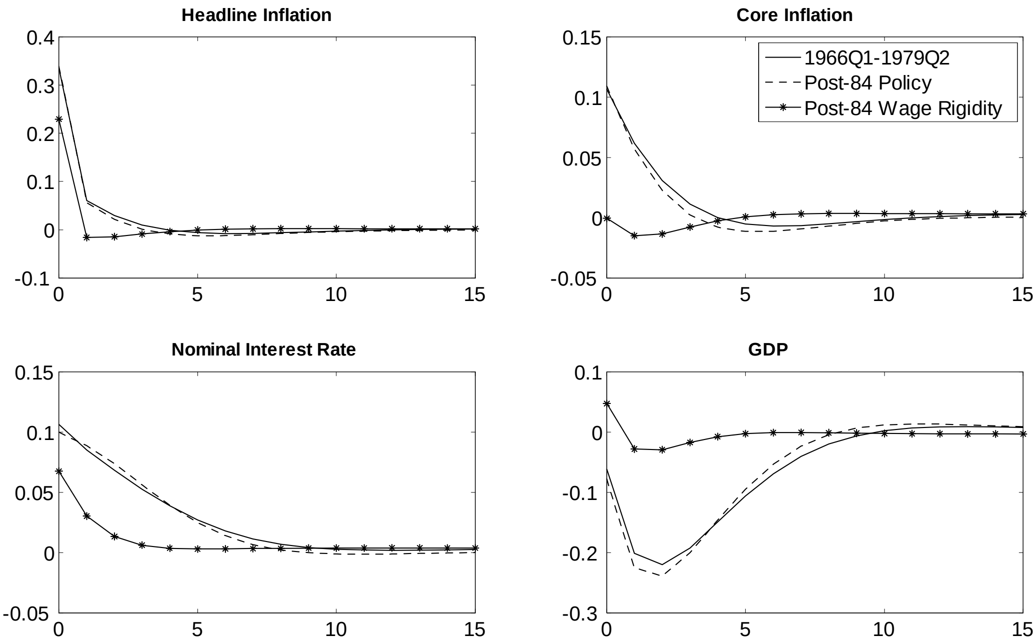

Figure 10: Counterfactual impulse response functions to a commodity price shock

Next, a counterfactual experiment will disentangle the driving force behind these changes over time. We divide the experiment into two categories. First, we combine the posterior mean estimates pertaining to the Taylor rule, i.e. ψ_π, ψ_x, $\psi_{\Delta y}$, ρ_R, π^*, and τ, of the post-1984 sub-sample with the remaining parameter estimates of the pre-1979 period which is called 'post-84 policy'. This exercise is designed to capture the role of monetary policy in reducing the effect of a given change in commodity prices. In the second category, we combine the posterior mean estimates of the pre-1979 period (including the policy parameters) with the estimated (lower) real wage rigidity from the post-1984 period, labelled 'post-84 wage rigidity'. This scenario is designed to capture the role of the decline in real wage rigidity as a possible explanation. Figure 10 depicts the impulse responses to a ten percent commodity price shock under the two alternative scenarios, while calibrating the remaining parameters at the posterior mean estimates of the pre-1979 period. Looking at the figure, we can see that the decline in the effects of commodity price shocks are mainly explained by a reduction in real wage rigidity. As argued earlier, real wage rigidity generates a trade-off between inflation and output gap stabilization. A shift toward more flexible wages implies a reduction in this trade-off, thereby explaining the smaller effects of the shocks in the more recent period. 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).

8 Robustness of determinacy

We now conduct a battery of sensitivity checks with respect to our main result. Directions involve (i) an alternative Taylor rule, (ii) alternative formulation of the boundary between the determinacy and indeterminacy region, (iii) flexible-price output gap, (iv) indexation to past inflation, and (v) using oil price data as an observable. For all these cases, the estimation is conducted while including both wage series. Table 6 summarizes the log-data densities and the posterior probabilities for all checks, while the parameter estimates are delegated to Tables A1 and A2 in the Appendix.

8.1 Alternative Taylor rule

Justiniano, Primiceri and Tambalotti (2013) propose an alternative formulation of the monetary policy rule that features a systematic response to deviations of annual inflation from a positive trend and to deviations of observed annual GDP growth from its steady state level.[26] Thus, we re-estimate the model by replacing the policy rule (5) with the following formulation:

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

We find a stronger response to output growth in both periods which is somewhat similar in magnitude to what Justiniano, Primiceri and Tambalotti (2013) report. Other than this, the determinacy result carries over (see Table 6, first row).

[26] Strictly speaking, the feedback rule specified by Justiniano, Primiceri and Tambalotti (2013) features a time-varying inflation target and does not include an output gap measure.

Table 6: Determinacy versus Indeterminacy (Robustness)

		Log-data density	Probability of det.
1966:I-1979:II	JPT Taylor rule	-287.06	0.9
	Boundary	-280.59	0.8
	Flex-price output gap	-276.72	0.9
	Indexation	-278.42	1
	Core CPI & Oil	-504.87	0.8
1984:I-2008:II	JPT Taylor rule	-290.13	1
	Boundary	-277.74	1
	Flex-price output gap	-280.45	1
	Indexation	-286.62	1
	Core CPI & Oil	-625.10	1

8.2 Crossing the boundary

The presence of positive trend inflation enriches the dynamics of the model and the usual Taylor principle, i.e. $\psi_\pi > 1$, is no longer a sufficient condition for local determinacy. The higher-order dynamics make it infeasible to analytically derive the indeterminacy conditions. To continue solving the model via Lubik and Schorfheide's (2004) method, where $M^*(\theta)$ is selected such that the responses of the endogenous variables to the fundamental shocks are continuous at the boundary, one needs to resort to numerical methods. So far, we have perturbed ψ_π to numerically trace the boundary. However, in the presence of trend inflation, this boundary becomes a complicated function of ψ_π along with the other Taylor Rule coefficients as well as the other structural parameters. As such, the indeterminacy test might become susceptible to how we trace the boundary. Hence, as a robustness check, we alternatively drag both the response to inflation ψ_π as well as the response to the output gap ψ_x. Nothing changes as we again find that data favors determinacy and the response to inflation is active, even during the Great Inflation.

8.3 Flexible-price output gap

In the analysis thus far, we have focused on the welfare-relevant output gap, defined as the deviation of actual output from its efficient level. Nevertheless, we have also estimated the model with the flexible-price output gap in the Taylor rule, defined as the deviation of actual output from its natural level prevailing under flexible prices. As pointed by Blanchard and Riggi (2013), the natural level of output fluctuates more with respect to oil price changes in a model with real wage rigidity. As a result, the flexible-price output gap turns out to be more volatile than the welfare-relevant output gap. We then find that the estimated response to the output gap turns out to be somewhat higher in the pre-1979 period. Yet, the findings that the pre-Volcker period is characterized by strongly active response to inflation and determinacy remain unchanged.

8.4 Indexation

So far, the model has been estimated assuming the absence of rule-of-thumb price-setting in light of Cogley and Sbordone's (2008) reported lack of intrinsic inertia in the GNK Phillips Curve. We now estimate the model while allowing for indexation. We follow Ascari et al. (2011) and estimate the degree of indexation to past inflation, which is also in line with Benati (2009). While finding some support for a moderate degree of indexation, the fourth row of Table 6 shows that the pre-Volcker period is still best characterized by determinacy.

8.5 Oil as an observable

Lastly, we investigate the sensitivity of our results to directly using real oil price data as an observable. Until now we have simultaneously employed both headline and core inflation measures as observables. This choice identifies the cost-push shocks as commodity price shocks in general (which includes the price of food and other commodities as well). For instance, the two inflationary episodes in the 1970s also featured sizeable food-price hikes as documented by Blinder and Rudd (2012). Since food has a much larger weight in the price indexes than energy, ignoring them might constitute a key omission. Nonetheless, we also check the robustness of our results to directly using percentage change of the real price of oil as an observable to identify the episodes of oil price shocks in isolation. As such, we use the West Texas Intermediate oil price data.[27] We deflate the nominal oil price by the core consumer price index to align it with the concept of real oil price in the model. The resulting series is then demeaned by its sub-sample mean prior to the estimation. We continue to use data on quarterly growth rate of GDP per capita, core CPI, the two (real) wage inflation series and the Federal Funds rate. Again, our results remain robust as you can see in the fifth row of Table 6.

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

9 Conclusion

Was the Great Inflation really caused by endogenous decisions, i.e. destabilizing monetary policies? This question has engaged many researchers since Clarida et al. (2000) who estimate the monetary policy rule in isolation, find a passive response to inflation which suggests that U.S. monetary policy before 1979 was consistent with equilibrium indeterminacy. Lubik and Schorfheide (2004) offer a parallel argument while treating indeterminacy as a property of a system (i.e. the New Keynesian model): loose monetary policy led to mercurial inflation. A similar conclusion appears in models with trend inflation. Coibion and Gorodnichenko (2011) using single-equation estimations and Hirose et al. (2017) employing general equilibrium estimations both suggest that the Great Inflation can be best understood as the result of equilibrium indeterminacy.

The current paper advances an alternative hypothesis that blames exogenous factors. This exercise is done in an estimated GNK economy which simultaneously considers trend inflation, real wage sluggishness and supply shocks in the form of oil. 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. Such an environment necessitates a full system estimation that takes into account this trade off such that the parameter estimates of the Taylor rule allow for the endogeneity of its targeted variables. Our analysis provides evidence for sluggish real wages and makes the case that the U.S. monetary policy before 1979 was inconsistent with equilibrium indeterminacy. In particular, we find that the Federal Reserve responded aggressively to inflation while its response to the output gap was almost negligible. Taken together, these responses imply that monetary policy had no destabilizing effect even in the Seventies. Phrased alternatively, we do not find empirical evidence for indeterminacy in the U.S. economy and this brings about an important implication for interpreting the Great Inflation: to a large extent it was driven by unfavorable supply shocks. We also estimate the model over the Great Moderation period and are able to account for the decline in macroeconomic volatility. We further document that oil price shocks are no longer as inflationary and a decline in real wage rigidity helps explain the remarkable resilience of the U.S. economy to sustained oil price fluctuations in the 2000s.

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10 Appendix

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

10.1 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. 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.

10.2 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.

10.2.1 Households

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

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

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

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

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

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

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

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

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

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

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

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

10.2.2 Firms

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

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

subject to the CES production technology

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

subject to the constraint

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

where

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

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

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

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

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

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

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

and

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

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

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

10.2.3 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:

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

10.2.4 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.

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

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, $\overline{x}$ is the steady state output gap, $\overline{g}$ is the gross steady state growth rate of the economy and $\varepsilon_{R,t}$ is an i.i.d. monetary policy shock. The output gap measures the deviation of the actual level of GDP Y_t from the efficient level of GDP, i.e. the counterfactual level of GDP that would arise in the absence of monopolistic competition, nominal price stickiness and real wage rigidity, Y_t^*. The central bank responds to a convex combination of headline and core inflation (with the parameter τ governing the relative weights; setting τ to one implies that the central bank responds to headline inflation only). The coefficients

ψ_π, ψ_x and ψ_g govern the central bank's responses to inflation, welfare-relevant output gap and output growth from their respective target values, and $\rho_R \in [0, 1]$ is the degree of policy rate smoothing .

10.3 Tables

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

	JPT rule	Boundary	Output gap	Indexation	CoreCPI-Oil
ψ_π	1.31 (0.17)	1.34 (0.37)	1.44 (0.15)	1.38 (0.15)	1.37 (0.27)
ψ_x	0.08 (0.08)	0.04 (0.03)	0.13 (0.11)	0.05 (0.04)	0.05 (0.08)
ψ_g	0.50 (0.18)	0.30 (0.15)	0.40 (0.15)	0.31 (0.13)	0.43 (0.18)
ρ_R	0.64 (0.06)	0.66 (0.07)	0.69 (0.05)	0.68 (0.06)	0.69 (0.05)
τ	0.77 (0.12)	0.55 (0.15)	0.47 (0.17)	0.58 (0.15)	0.38 (0.15)
π^*	1.37 (0.21)	1.34 (0.18)	1.38 (0.16)	1.37 (0.19)	1.47 (0.20)
R^*	1.57 (0.21)	1.50 (0.20)	1.53 (0.19)	1.53 (0.21)	1.65 (0.20)
g^*	0.47 (0.07)	0.46 (0.07)	0.44 (0.07)	0.45 (0.07)	0.43 (0.08)
ξ	0.62 (0.03)	0.59 (0.04)	0.60 (0.04)	0.59 (0.04)	0.64 (0.04)
γ	0.91 (0.02)	0.89 (0.04)	0.87 (0.04)	0.90 (0.03)	0.91 (0.03)
h	0.43 (0.07)	0.38 (0.06)	0.37 (0.06)	0.40 (0.07)	0.30 (0.06)
ω	–	–	–	0.44 (0.08)	–
ρ_d	0.68 (0.08)	0.74 (0.07)	0.76 (0.07)	0.76 (0.07)	0.81 (0.10)
ρ_ν	0.78 (0.08)	0.85 (0.07)	0.89 (0.05)	0.85 (0.06)	0.75 (0.13)
σ_s	17.33 (1.64)	17.04 (1.54)	17.25 (1.61)	17.22 (1.56)	17.21 (1.55)
σ_g	0.51 (0.09)	0.50 (0.09)	0.49 (0.08)	0.45 (0.08)	0.56 (0.09)
σ_r	0.27 (0.04)	0.31 (0.04)	0.30 (0.04)	0.29 (0.03)	0.32 (0.04)
σ_d	2.10 (0.33)	1.60 (0.44)	1.68 (0.30)	1.97 (0.35)	2.07 (0.37)
σ_ν	0.34 (0.07)	0.41 (0.10)	0.40 (0.09)	0.42 (0.08)	0.36 (0.10)
σ_ζ	0.49 (0.21)	0.44 (0.14)	0.46 (0.19)	0.45 (0.19)	0.43 (0.16)
$M_{s,\zeta}$	0.05 (0.94)	0.16 (0.83)	−0.08 (0.93)	0.07 (0.96)	0.28 (0.89)
$M_{g,\zeta}$	−0.07 (1.02)	0.08 (0.94)	0.01 (0.99)	0.00 (0.98)	0.10 (0.97)
$M_{r,\zeta}$	0.06 (0.98)	−0.02 (0.91)	−0.01 (0.96)	0.00 (0.97)	−0.29 (0.96)
$M_{d,\zeta}$	0.00 (0.98)	0.12 (0.94)	0.16 (1.04)	0.07 (1.00)	0.19 (0.99)
$M_{\nu,\zeta}$	−0.15 (1.01)	0.02 (0.94)	−0.06 (1.00)	0.01 (1.01)	0.04 (0.91)
λ	1.00 (0.25)	1.09 (0.25)	1.08 (0.22)	1.09 (0.21)	0.97 (0.28)
σ_{w_1}	0.34 (0.11)	0.36 (0.09)	0.38 (0.09)	0.39 (0.09)	0.31 (0.11)
σ_{w_2}	0.51 (0.09)	0.42 (0.11)	0.43 (0.10)	0.44 (0.09)	0.51 (0.10)

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

	JPT rule	Boundary	Output gap	Indexation	CoreCPI-Oil
ψ_π	2.92 (0.29)	2.95 (0.30)	2.16 (0.21)	3.06 (0.33)	2.86 (0.35)
ψ_x	0.29 (0.13)	0.11 (0.05)	0.13 (0.10)	0.17 (0.08)	0.07 (0.04)
ψ_g	0.58 (0.16)	0.61 (0.13)	0.58 (0.14)	0.51 (0.12)	0.60 (0.13)
ρ_R	0.62 (0.06)	0.71 (0.04)	0.72 (0.04)	0.70 (0.04)	0.74 (0.04)
τ	0.19 (0.08)	0.13 (0.05)	0.20 (0.07)	0.12 (0.05)	0.16 (0.07)
π^*	0.96 (0.10)	0.94 (0.09)	0.94 (0.07)	0.94 (0.09)	0.96 (0.09)
R^*	1.48 (0.15)	1.43 (0.14)	1.44 (0.14)	1.47 (0.14)	1.46 (0.14)
g^*	0.22 (0.05)	0.18 (0.04)	0.14 (0.04)	0.18 (0.05)	0.15 (0.05)
ξ	0.68 (0.03)	0.61 (0.05)	0.67 (0.04)	0.51 (0.05)	0.64 (0.04)
γ	0.65 (0.07)	0.44 (0.12)	0.57 (0.11)	0.30 (0.11)	0.60 (0.09)
h	0.30 (0.05)	0.24 (0.05)	0.30 (0.06)	0.21 (0.05)	0.31 (0.06)
ω	–	–	–	0.30 (0.08)	–
ρ_d	0.82 (0.04)	0.85 (0.04)	0.85 (0.04)	0.84 (0.03)	0.83 (0.04)
ρ_ν	0.94 (0.04)	0.99 (0.01)	0.98 (0.01)	0.99 (0.01)	0.98 (0.01)
σ_s	14.86 (1.03)	14.92 (1.06)	14.98 (1.05)	14.81 (0.99)	12.76 (0.87)
σ_g	0.56 (0.08)	0.43 (0.08)	0.53 (0.09)	0.43 (0.08)	0.45 (0.05)
σ_r	0.14 (0.01)	0.18 (0.02)	0.17 (0.02)	0.18 (0.02)	0.17 (0.02)
σ_d	1.57 (0.21)	1.21 (0.20)	1.18 (0.16)	1.12 (0.17)	1.21 (0.17)
σ_ν	0.44 (0.08)	0.78 (0.16)	0.70 (0.13)	0.92 (0.14)	0.62 (0.12)
σ_ζ	0.42 (0.14)	0.53 (0.25)	0.44 (0.17)	0.43 (0.15)	0.48 (0.17)
$M_{s,\zeta}$	−0.18 (0.98)	0.08 (0.98)	−0.05 (0.95)	0.17 (0.98)	−0.15 (0.98)
$M_{g,\zeta}$	−0.07 (0.94)	0.01 (0.94)	−0.06 (0.96)	0.24 (0.96)	−0.01 (0.99)
$M_{r,\zeta}$	−0.17 (0.95)	−0.11 (0.95)	0.00 (0.94)	−0.34 (0.96)	−0.04 (0.98)
$M_{d,\zeta}$	0.07 (0.99)	0.20 (0.98)	0.04 (0.93)	−0.03 (0.91)	0.01 (0.98)
$M_{\nu,\zeta}$	0.13 (0.97)	−0.04 (0.92)	0.05 (0.96)	−0.05 (0.99)	−0.08 (0.95)
λ	0.15 (0.09)	0.29 (0.08)	0.31 (0.08)	0.30 (0.07)	0.33 (0.10)
σ_{w_1}	0.73 (0.08)	0.66 (0.07)	0.59 (0.07)	0.67 (0.06)	0.63 (0.07)
σ_{w_2}	0.42 (0.04)	0.38 (0.04)	0.36 (0.03)	0.38 (0.04)	0.37 (0.04)

Tables A1 and A2 report the posterior mean along with the standard deviations in parenthesis.