Inflation Sensitivity To Monetary Policy: What Has Changed since the Early 1980's?

Roberto Pancrazi and Marija Vukotić*

June, 2018

Abstract

Have conventional monetary policy instruments maintained the same ability to accommodate undesirable effects of shocks throughout the post-war period? Or has the changed economic environment characterizing the last thirty years diminished the sensitivity of macroeconomic volatility to systematic changes in the conduct of monetary policy? The answer is *no* to the first question and, consequently, *yes* to the second question. We estimate a medium-scale New-Keynesian model in two subsamples, 1955-1979 and 1984-2012, and find that the sensitivity of inflation variance to changes in conventional monetary policy has declined. We document that the changed properties of the labor market largely contributed to this decline.

JEL Classification: E52, E32.

Keywords: Monetary Policy Effectiveness, New-Keynesian Model, Inflation Stabilization.

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[*] Pancrazi: University of Warwick, Economics Department, Coventry CV4 7AL, United Kingdom (e-mail: r.pancrazi@warwick.ac.uk.); Vukotić: University of Warwick, Economics Department, Coventry CV4 7AL, United Kingdom (e-mail: m.vukotic@warwick.ac.uk). We thank the editor and two anonymous referees who made valuable suggestions for improving the paper.

1 Introduction

The U.S. economy experienced some fundamental changes around the early 1980's; whereas for a long time researchers have focused on understanding the sources behind the evident reduction in macroeconomic volatility, a phenomenon referred to as the "Great Moderation"[1], more recently several authors have argued that the changes after early 1980's have been even more profound. For example, Galí and Gambetti (2009) and Barnichon (2010) document an altered pattern of comovements among output, hours, and labor productivity after the early 1980's, attributing part of this changed dynamics to a shift in the composition of exogenous shocks; Nucci and Riggi (2013) and Galí and Van Rens (2014) document similar patterns and relate them to structural shifts on the labor market; Foroni et al. (2015) find that labor market shocks became more important drivers of macroeconomic fluctuations in the post-1980.

Motivated by this evidence, our paper asks the following question: how have these changes after the early 1980's affected the ability of monetary policy to smooth out aggregate fluctuations? With the purpose of clarifying this economic question, consider a fairy simple three-equation New Keynesian model, composed of the New Keynesian Phillips curve, an aggregate demand curve, and a monetary policy schedule, for example a Taylor rule. In this context, it is well know that by increasing the systematic response of interest rate to inflation, the monetary policy is able to reduce fluctuations in nominal and real macroeconomic variables. Hence, using this conventional monetary policy tool, monetary policy is effective in reducing macroeconomic fluctuations. This consideration squares with the findings of Clarida, Galí, and Gertler (2000), Cogley and Sargent (2001), Romer and Romer (2002), and Boivin and Giannoni (2006), among others, who conclude that an increase in monetary policy's response to inflation during Volcker era indeed played a dominant role in the reduction of macroeconomic volatility. But, how sensitive is the reduction of macroeconomic volatility to changes in this type of conventional monetary policy tools? And how has this sensitivity evolved over time?

To answer these questions, we start from the simple observation that the ability of monetary policy to reduce macroeconomic volatility can be affected by various factors, such as the structure of the economy, the relative importance of exogenous shocks, as well as their persistence. We then consider

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[1] Broadly speaking, one strand of this literature attributes most of this reduction to smaller macroeconomic shocks, another strand of the literature attributes it mainly to the more systematic response of monetary policy to fluctuations in economic conditions.This first explanation of the Great Moderation is known as the "good luck" hypothesis. See, for example, Kim and Nelson (1999), Stock and Watson (2003a,b), Ahmed, Levin, and Wilson (2004), Primiceri (2005), and Liu, Waggoner, and Zha (2009). The second explanation is known as the "good policy" hypothesis. See, for example, Clarida, Galí, and Gertler (2000), Cogley and Sargent (2001, 2005), Blanchard and Simon (2001), Benati and Surico (2009), and Boivin (2006). Other explanations have also been proposed in the literature; for example, a change in inventories management, proposed by McConnell and Perez-Quiros (2000) and Kahn, McConnell, and Perez-Quiros (2002), and financial innovation, proposed by Dynan and Elmendorf (2006), among others.

a fairly standard medium-scale dynamic stochastic general equilibrium (DSGE) model as in Smets and Wouters (2007) and, as standard in the Great Moderation literature, estimate it in two subsamples: the pre-1980 and post-1980 sample period. This approach allows us to consider all of the above factors, while being agnostic about their relative importance in driving changes between the two subsamples. Finally, we propose a measure of the *sensitivity* of macroeconomic volatility to changes in conventional monetary policy tools. This measure captures by *how much* the variance of a macroeconomic variable, such as inflation or output gap, varies as a consequence of a small change in the systematic response of a monetary authority to inflation.

We find that the *sensitivity* of inflation volatility has declined drastically.[2] How do we interpret this result? We argue that the economic environment at the end of the 1970's was particularly favorable for a relatively small increase in the systematic response to inflation to have a large effect on inflation volatility. In fact, because in this period the economic environment was such that the *sensitivity* of inflation volatility to changes in conventional policy tools was quite high, the monetary policy was very effective in reducing inflation volatility by increasing the Taylor-rule parameter, as pointed out in the literature. However, in the last three decades, the economic environment, characterized by structural changes and the estimated changes in the exogenous shocks, brought about a large decline in the *sensitivity*. Therefore, should a policymaker nowadays need to achieve a large reduction in inflation variance, it would need to respond to inflation much more aggressively. Importantly, in this paper we focus only on conventional monetary policy tools, namely Taylor-rule manipulations, and we abstract from any non-conventional tools, such as quantitative easing, since we believe that the latter was prompted by the exceptional severity of the recent crisis. We believe that our novel finding is particularly relevant nowadays, when monetary policy makers are starting to rely on conventional tools again.

Three remarks are in order. First, one should interpret our definition of *sensitivity* as a local measure, since it depends on the structure of the economy, on the shocks, and on the interest rate rule in place. Second, our definition of *sensitivity* aims to measure the magnitude of monetary policy's effectiveness proposed in the literature, such as the one used by Boivin and Giannoni (2006). Our measure thus allows to understand how the evolution of the economic environment has affected the potential of monetary policy to smooth undesired shocks by altering its response to inflation. In order to abstract from any level effects, we also define the *elasticity* of the sensitivity, which depicts how responsive the variance of a macroeconomic variable is to the same change in the monetary policy parameter, ceteris paribus. Third, the implicit assumption, as made in most of the related literature, is that inflation expectations

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[2] We also analyze the *sensitivity* of output gap volatility and document that it is low and roughly unchanged across the two subsamples. Therefore, we focus most of our attention on explaining changes in the *sensitivity* of inflation volatility.

are anchored in both subsamples.

By using a medium-scale DSGE model as in Smets and Wouters (2007) as our laboratory, we focus on estimating the *sensitivity* (and its *elasticity*) of inflation variance to changes in conventional monetary policy tools.[3] We estimate the model with Bayesian techniques in the two subsamples, pre-1980 and post-1980 period. The estimated model reveals that the *sensitivity* of inflation variance to systematic responses to inflation in the Taylor rule has drastically declined, from -5.2 in the first subsample to -0.2 in the second subsample. While the negative signs, consistent with the literature, suggest that stronger response to inflation leads to the reduction in inflation volatility, the large decline in the magnitude of the sensitivity suggests that responsiveness of inflation volatility to changes in monetary policy declined drastically. Similarly, the corresponding *elasticity* also largely declined, from -5.6 in the first subsample to -2.2 in the second subsample. This result has the following interpretation: a 1 percent increase in the magnitude of the response to inflation in the Taylor rule leads to a 5.6 percent decline in inflation variance in an economy that mimics the pre-1980 economy, and only to a 2.2 percent decline in an economy that mimics the post-1980 economy. In other words, while the pre-1980 economic environment was favorable for a systematic change in the conduct of monetary policy to induce a large reduction in inflation volatility, the post-1980 economic environment saw an inflation volatility that was much less responsive to any *further* monetary policy adjustments.

We perform several counterfactual exercises to disentangle the factors that led to the decline of our *sensitivity* measure. In particular, following a similar approach as in Boivin and Giannoni (2006), we divide all parameters of the model into four subsets: policy parameters (Taylor-rule parameters), structure parameters (technology, preference, etc.), variance of the shocks, and the persistence of the shocks. We then ask the following question: What would have the *sensitivity* of inflation variance to monetary policy changes been in the last thirty years had a subset of parameters remained the same as in the pre-Volcker era? By answering this question, we determine two main causes of the reduced *sensitivity*: relatively high inflation coefficient in the post-1980 Taylor rule, which limited the ability of monetary authority to further stabilize macroeconomic volatility by responding to inflation even more aggressively, and the estimated change in persistence of the exogenous shocks, a cause that has been completely overlooked by the literature so far. Among the estimated exogenous shocks, changes in the wage markup shock turn out to be crucial. Specifically, if all the parameters of the model except for the persistence of the wage markup process were kept at their second-subsample values, the *sensitivity* of

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[3] The use of this model is quite standard in the literature. The model features several frictions, both nominal and real. In particular, it features sticky nominal price and wage setting that allows for backward inflation indexation, habit formation in consumption and investment adjustment costs, variable capital utilization and fixed costs in production. The dynamics is driven by seven orthogonal structural shocks: neutral and investment-specific technology shocks, risk premium shock, price and wage markup shocks, exogenous spending shock and monetary policy shock.

inflation variance to monetary policy changes, in terms of elasticity, would still be quite large, equal to -3.44, which is the value much closer to its first subsample estimate. Repeating the same exercise for all other shocks leads to elasticities almost identical to those in the second subsample. This result suggests that, among the persistence parameters of the exogenous shocks, only the wage markup persistence could have caused the decline in sensitivity.

Our results directly relate to the debate on the sources of Great Moderation. They closely link the two prevalent explanations of this phenomenon: while they are in line with the "good policy" hypothesis which claims that monetary policy was particularly effective in reducing inflation variance, they add yet another important dimension to the "good luck" hypothesis by documenting that one of the reasons behind this high effectiveness was not only more aggressive response of monetary policy to inflation but also the nature of the exogenous shocks (both persistence and variance) during that time period. To put it in the context of the language used in the literature, "good luck", interpreted as a change in the properties of the exogenous shocks, amplified the effects of "good policy".

It is important to remark that our counterfactuals should be interpreted with care, since they rely on the assumption that the Smets and Wouters (2007)'s DSGE model is a good representation of the true data generating process. Recently, this model has been criticized by Chari, Kehoe, and McGrattan (2009), who point out that four of the seven shocks considered in this model are not structural. In light of this view, it would conceptually be misleading to independently separate the set of the structural parameters from the set of the parameters that define the exogenous shocks. Nevertheless, we believe that our counterfactual exercises are still useful, because they point out that the reduced sensitivity of inflation variance to policy changes mainly relates to what Smets and Wouters (2007) view as persistence of the wage markup shock, and to what Chari, Kehoe, and McGrattan (2009) view as labor wedge.[4]

Finally, in order to gain some intuition for our results, we consider a very simple New Keynesian model, as described in Galí (2009). Although stylized, this model provides better understanding of our results by showing, in a close form, how the *sensitivity* of inflation volatility to changes in monetary authority's response to inflation in the Taylor rule, depends on the level of that response and on the persistence of the labor market shock. Specifically, we show that, while the *sensitivity* monotonically declines with the increase in the response to inflation, the relationship between the persistence of the labor market shock and the *sensitivity* is non-monotonic. This means that for large values of the persistence, sensitivity is very high implying large potential of monetary policy to stabilize inflation variations. However, as the persistence of labor market shock decreases so does the potential of monetary policy to stabilize inflation. Interestingly, the relationship between monetary policy parameters, persistence of

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[4] This labor wedge can be interpreted, for example, as fluctuations in the bargaining power of unions or as fluctuations in the value of the leisure of consumers.

the labor market shock, and the effectiveness of monetary policy is highly non-linear.

The rest of the paper is organized as follows. Section 2 starts from the state-space representation of a generic DSGE model in order to illustrate how sensitivity of macroeconomic volatility to changes in monetary policy can be influenced by various factors in the economy. Section 3 lays out a modeling choice, as well as the estimation results. Section 4 uses these results to construct counterfactual scenarios which help us in identifying the causes of the decline in the effectiveness. Section 5 offers some intuition for the obtained results by using a simple three-equation New Keynesian model in which all the results can be derived analytically, as in Galí (2009). Section 6 concludes.

2 The Sensitivity of Macroeconomic Volatility to Monetary Policy - A Simple Theoretical Illustration

In this section we define the variables of interest for our analysis, namely the *sensitivity* of macroeconomic volatility to monetary policy changes, both in terms of level and elasticity.

Consider an equilibrium of a DSGE model that has the following $ABCD$ representation, in its first-order approximation form, as in Fernandez-Villaverde et al. (2007):

$$X_t = A(\Theta, \Phi, \Psi) X_{t-1} + B(\Theta, \Phi, \Psi)\varepsilon_t, \tag{1}$$

$$Y_t = C(\Theta, \Phi, \Psi) X_{t-1} + D(\Theta, \Phi, \Psi)\varepsilon_t. \tag{2}$$

Here, X_t is an $n_X \times 1$ vector of state variables, Y_t is an $n_Y \times 1$ vector of control variables, and ε_t is an $n_\varepsilon \times 1$ vector of white noise exogenous disturbances with the variance-covariance matrix Σ_ε. The matrices A, B, C and D are functions of parameters that can generally be divided into three sets. The first set of parameters, Θ, characterizes the overall structure of the economy, such as preferences, production technology, etc. The second set of parameters, Φ, characterizes monetary policy behavior, described, for example, by the Taylor-rule parameters. The third set of parameters, Ψ, characterizes the autoregressive structure of the exogenous processes. For example, if we assumed that these processes had a first-order autoregressive structure, Ψ would gather all the first-order autoregressive coefficients. We also define a fourth set of parameters, Σ_ε, which collects the variances of the exogenous shocks. Since the $ABCD$ representation is derived from the first-order approximation of the model, the fourth set of parameters, Σ_ε, will not affect the matrices A, B, C, and D, but will directly affect the second moments of the macroeconomic variables, as explained next.

The $ABCD$ representation above delivers simple analytical expressions for the second moments of the model. For example, the variances of X_t and Y_t are given by:

$$\begin{aligned} \Sigma_Y = \quad & \mathbb{E}(YY') = \quad & C(\Theta,\Phi,\Psi)\Sigma_X C'(\Theta,\Phi,\Psi) + D(\Theta,\Phi,\Psi)\Sigma_\varepsilon D'(\Theta,\Phi,\Psi), \\ \Sigma_X = \quad & \mathbb{E}(XX') = \quad & A(\Theta,\Phi,\Psi)\Sigma_X A'(\Theta,\Phi,\Psi) + B(\Theta,\Phi,\Psi)\Sigma_\varepsilon B'(\Theta,\Phi,\Psi). \end{aligned}$$

These expressions clearly show that the variance of macroeconomic variables depends on the deep structure of the economy, characterized by the reduced form parameters A, B, C and D, and on the variance of the shocks, Σ_ε.

One of the most prominent explanations of the causes of the Great Moderation is the so called "good policy" hypothesis. This hypothesis states that a change in the policy parameters, Φ, and in particular an increase in the response to inflation in the Taylor rule during the Volcker era, was the main contributor to the reduction in the overall macroeconomic volatility.[5] Given our notation, this hypothesis can technically be written as:

$$\Sigma_Y(\Theta_1,\Phi_1,\Psi_1) > \Sigma_Y(\Theta_1,\Phi_2,\Psi_1),$$

where the two subscripts denote the sets of parameters that describe the economy in the first subsample (pre-1980 period) and in the second subsample (post-1980 period), respectively. In other words, the good policy hypothesis has been tested in the literature by isolating the role that a change in the monetary policy conduct, captured by the shift from Φ_1 to Φ_2, has played in the reduction of macroeconomic volatility. This statement can be rigorously written as $\frac{\Delta\mathbb{E}(Y'Y)}{\Delta\Phi} < 0$, implying that a change in the response of the monetary policy to inflation at the beginning of the Volcker era, from Φ_1 to Φ_2, caused a reduction in the volatility of macroeconomic variables. In other words, a change in the monetary policy conduct that occurred around the early 1980's was particularly effective.

In this paper we investigate a novel question, not studied in the literature: how sensitive is the macroeconomic volatility to marginal changes in the conventional-monetary policy tools, which are, in this context, the parameters of the systematic component of the Taylor rule? Notice that the effects of a change in monetary policy on the second moments of macroeconomic variables depend on the characteristics of the economy, described by the set of parameters A, B, C, and D. For example, let us

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[5] Several works, for example, Clarida, Galí, and Gertler (2000), Cogley and Sargent (2001), Romer and Romer (2002), and Boivin and Giannoni (2006), have concluded that more aggressive monetary policy indeed played a dominant role in this reduction. At the same time, the response of macroeconomic variables to a particular exogenous shock could change due to systematic changes in the conduct of monetary policy. Gambetti, Korobilis, Tsoukalas, and Zanetti (2017), for example, show that changed comovements of macroeconomic variables in response to news shocks over time are tightly linked to the systematic changes in the conduct of monetary policy.

assume that Volcker in 1979 decided to increase the response to inflation.[6] In such a case, the magnitude of the effect that this policy change has on the volatility of macroeconomic variables would depend on the value of the parameters A, B, C, and D at that particular moment. If a new Chairman in the future were to make the exact same change in an economy characterized by a different structure, the effect on a macroeconomic variable would potentially be different. In fact, if the structure of the economy changes, a similar monetary policy change would, in principle, have effects of different magnitudes. Therefore, in this paper we first estimate the changes in the structure of the economy in the two subsamples (pre-1980 and post-1980) and then investigate how these estimated changes over the last three decades have affected the ability of a monetary authority to further stabilize the economy.

Let us now define the objects of interest for our analysis. In particular, we define the *sensitivity*, denoted by ϵ, as the effect of a marginal change in the monetary policy parameters, Φ, on the variance of an endogenous variable, i.e.:

$$\epsilon\left(\Theta, \Phi, \Psi, \Sigma_{\varepsilon}\right) = \frac{\partial \mathbb{E}(YY')}{\partial \Phi}. \tag{3}$$

The sensitivity defined as above can be affected in two ways. First, it will be altered by any change in the parameters of the matrices A, B, C and D in equations (1) - (2). These parameters might change for different reasons, such as due to a change in the conduct of monetary policy, as the one documented in the post-1980 era, due to a change in the structure of the economy, as documented by Kahn, McConnell, and Perez-Quiros (2002), or due to a change in the propagation of the shocks, as documented by Pancrazi (2015). Second, the sensitivity will also be altered by an unequal change in the variances of the shocks, captured by a change in the elements of the matrix Σ_{ε}.

This measure of the *sensitivity* is affected by the level effects. In fact, it depends on the value of variance of the variable in question and on the value of the monetary policy parameter itself. To abstract from these level effects, we construct a measure of the *elasticity* of sensitivity, denoted by ϵ^L, and define it as:

$$\epsilon^{L}\left(\Theta, \Phi, \Psi, \Sigma_{\varepsilon}\right) = \frac{\partial \mathbb{E}(YY')}{\partial \Phi} \frac{\Phi}{\mathbb{E}(YY')}.^{7} \tag{4}$$

In the next section, we compute both measures using a standard DSGE model. In addition to quantifying the changes in both of these measures, we also identify the sources behind them by conducting various counterfactual experiments. Also, equation (3) allows us to identify which shocks have become easier/harder to accommodate, ultimately altering the potential of monetary policy to further stabilize macroeconomic fluctuations.

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[6] See Benati and Goodhart (2010) for a comprehensive historical account of monetary policy regimes from 1978 to 2008.

[7] The division and the product are element-by-element operations.

3 Empirical Strategy

3.1 DSGE model

We use a medium-scale DSGE model as in Smets and Wouters (2007) as our laboratory for computing an accurate measure of the sensitivity of monetary policy's effectiveness and its elasticity.[8] Importantly, this approach allows us to estimate possible changes in the macroeconomic environment that, as seen in the last section, might alter the degree by which the monetary policy is able to affect macroeconomic stability. Since this model is standard in macroeconomics literature and since it is thoroughly elaborated in the original paper, we do not report all the equations of the model here. Instead, here we simply summarize its main components.[9]

The estimated model features several frictions, both nominal and real. In particular, it features sticky nominal price and wages setting that allows for backward inflation indexation, habit formation in consumption and investment adjustment costs, variable capital utilization and fixed costs in production. As in the original Smets and Wouters (2007)'s model, the dynamics are driven by seven orthogonal structural shocks: neutral and investment-specific technology shocks, risk premium shock, price and wage markup shocks, exogenous spending shock and monetary policy shock.

In this model, the monetary authority follows a generalized Taylor rule by gradually adjusting the policy-controlled interest rate, r_t, in response to inflation, π_t, and output gap, $y_t - y_t^p$, defined as the difference between actual and potential output (see Taylor (1993)), as follows:

$$r_t = \phi_r r_{t-1} + (1-\phi_r)\{\phi_\pi \pi_t + \phi_Y (y_t - y_t^p\} + \phi_{\Delta y}\left[(y_t - y_t^p) - (y_{t-1} - y_{t-1}^p)\right]. \tag{5}$$

Potential output is defined as the level of output that would prevail under flexible prices and wages in the absence of the two markup shocks. The parameter ϕ_r captures the degree of interest-rate smoothing, ϕ_π captures the response to inflation, ϕ_Y captures the response to output gap, and $\phi_{\Delta y}$ captures the short-run feedback from the change in the output gap.[10]

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[8] We choose to conduct our analysis using the Smets and Wouters (2007) model for two reasons. First, since this model has been consistently used in the literature to analyze monetary policy, it will be easier to put our results into context. Second, this model is at the core of models used by Central Banks to conduct policy analysis and, therefore, we believe it represents a good benchmark. As Tovar (2009) describes, some Central Banks that have developed DSGE models are the Bank of Canada (ToTEM), Bank of England (BEQM), Central Bank of Chile (MAS), Central Reserve Bank of Peru (MEGA-D), European Central Bank (NAWM), Norges Bank (NEMO), Sveriges Riksbank (RAMSES) or the US Federal Reserve (SIGMA). Also, multilateral institutions like the IMF have developed their own DSGE models for policy analysis (GEM, GFM, or GIMF).

[9] A complete description of the model can be found in the Model Appendix of Smets and Wouters (2007), available at https://assets.aeaweb.org/assets/production/articles-attachments/aer/data/june07/20041254_app.pdf.

[10] When analyzing the effects of monetary policy parameters, we focus only on the inflation parameter in the Taylor rule. Our choice is motivated by the two facts. First, most of the literature equates good policy, or a changed monetary policy

3.2 Estimation Strategy

We estimate the model with Bayesian techniques using as observables the same seven quarterly macroeconomic U.S. time series as in Smets and Wouters (2007): the log difference of real GDP, real consumption, real investment and the real wage, log hours worked, the log difference of the GDP deflator, and the federal funds rate. We update the dataset to take into account observations until 2012. We estimate the model for the 1955-1979 sample and for the 1984-2012 sample. As in Smets and Wouters (2007), Boivin and Giannoni (2006) and Ahmed, Levin, and Wilson (2004), among others, our benchmark specification for the second subsample omits the transition period between 1979-1983 to better account for possible breaks between the two subsamples. Nevertheless, our results are robust to including this period in the second subsample, as we redo the analysis for 1980-2012 subsample as well. In addition, one might argue that the results will be affected when we include a Great Recession period, a period characterized by the nominal interest rates close to zero and numerous unconventional monetary policy interventions as a consequence. To address this issue, we perform a robustness check where we restrict the second subsample to the period 1984-2007. We show that our main findings are not affected by the sample choice. As in Smets and Wouters (2007), some parameters are fixed in the estimation procedure, since they are hard to identify: the depreciation rate is fixed at 0.025 (on a quarterly basis); the steady-state markup in the labor market is set at 1.5; and the curvature parameters of the Kimball aggregators in the goods and labor market are both set at 10.

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conduct in the early 1980's, with the more aggressive response of monetary policy to inflation. Second, our estimates will also show that the response to output gap was almost identical before and after 1980's.

3.3 Parameter Estimates

Table 1: Estimated Model Parameters

	Sample 1 1955-1979	Sample 2 (break) 1984-2012	Sample 2 (short) 1984-2007	Sample 2 (no break) 1980-2012
Standard Deviation of the Shocks		Σ_ε		
Sd technology	0.60	0.45	0.47	0.42
Sd risk-premium	0.25	0.03	0.05	0.04
Sd govt-spending	0.49	0.36	0.43	0.37
Sd investment specific	0.40	0.31	0.29	0.26
Sd monetary	0.18	0.11	0.20	0.11
Sd price markup	0.21	0.11	0.11	0.10
Sd wage markup	0.20	0.40	0.37	0.27
Persistence of the Shocks		Ψ		
AR(1) technology	0.99	0.99	0.99	0.99
AR(1) risk-premium	0.19	0.94	0.94	0.95
AR(1) govt-spending	0.98	0.97	0.97	0.96
AR(1) investment specific	0.82	0.73	0.86	0.77
AR(1) monetary	0.32	0.34	0.10	0.31
AR(1) price markup	0.74	0.93	0.91	0.94
AR(1) wage markup	0.99	0.41	0.68	0.51
Monetary Policy		Φ		
Taylor Rule: inflation	1.20	1.54	1.89	1.75
Taylor Rule: interest-rate smoothing	0.77	0.85	0.78	0.84
Taylor Rule: output gap	0.01	0.01	0.01	0.01
Taylor Rule: previous output gap	0.17	0.19	0.21	0.20
Structure		Θ		
Adjustment cost	4.10	5.33	5.63	6.00
Intertemporal EOS	1.83	1.23	1.41	1.05
Habit formation parameter	0.60	0.51	0.50	0.52
Wage stickiness	0.84	0.89	0.88	0.86
Labor supply elasticity	1.49	1.01	2.00	1.95
Price stickiness	0.80	0.80	0.81	0.73
Wage indexation wages	0.58	0.39	0.48	0.40
Price indexation prices	0.31	0.21	0.25	0.29
Capacity utilization elasticity	0.34	0.86	0.81	0.75
Share of fixed costs	1.44	1.57	1.49	1.52
Quarterly steady state inflation rate	0.62	0.65	0.61	0.57
100*(discount factor - 1)	0.22	0.26	0.22	0.20
Share of capital	0.24	0.18	0.20	0.20

Note: This table reports the estimated parameters as the medians of the posterior distributions in the Smets and Wouters (2007) model estimated over several time periods: the first subsample (1955:1-1979:4, first column), the second subsample with (1984:1-2012:1, second column) and without (1984:1-2007:1, third column) Great Recession period, and the second subsample with an earlier starting date (1984:1-2012:1, fourth column). The parameters are divided into four groups as described above. The technical parameters of the estimation procedure, including prior distributions, are the same as in Smets and Wouters (2007).

Table 1 reports the posterior medians of all the parameters in the first subsample (1955-1979) and in the second subsample (1984-2012), as well as for the two additional specifications that demonstrate the robustness of our results.[11] Several results emerge.

First, the different magnitudes of the standard deviations of the shocks in the two subsamples, gathered in the Σ_ε matrix, are consistent with the findings of the Great Moderation literature, as in Stock and Watson (2003b), Primiceri (2005), Sims and Zha (2006), Arias, Hansen, and Ohanian (2007), Mojon (2007), among others. In fact, the standard deviation of all the shocks (technology, risk premium, government spending, investment specific, monetary, and price markup) except the wage markup shock, has declined, although unevenly. Second, the estimates suggest that also the persistence of the shocks has somewhat changed during the second subsample. While the persistence of risk premium has increased, the persistence of price markup, technology, government spending, and monetary shocks remained relatively constant, and the persistence of the investment specific shock and of the wage markup shock largely declined. The latter finding is crucial because we will show that changes in the sensitivity to changes in monetary policy can be largely attributed to the changes in the nature of the labor market shocks. Recently Chari, Kehoe, and McGrattan (2007, 2009) have highlighted the importance of disturbances in the labor-market equilibrium equation for explaining the overall variations, but have at the same time criticized Smets and Wouters (2007)'s interpretation of the wage markup shock. In particular, they point out that four of the seven shocks considered in this model, with the wage markup shock being one of them, are not structural. That is, they argue that introducing the wage markup shock amounts to mechanically inserting a labor wedge into the model, where the wedge can be interpreted in at least two ways, for example as fluctuations in the bargaining power of unions or as fluctuations in the value of the leisure of consumers. Our finding supports the idea that the labor market sector of the model is crucial for evaluating policy effectiveness, as the change in its properties after early 1980's has played a major role in reducing responsiveness of inflation volatility to monetary policy changes. Third, regarding the monetary policy parameters, our estimates capture the more aggressive monetary policy that characterized the post-1980 period, as also estimated by Taylor (1999), Clarida, Galí, and Gertler (2000), Cogley and Sargent (2001), Romer and Romer (2002), and Boivin and Giannoni (2006), among others. In fact, the response of the monetary authority to inflation has largely increased from values slightly above 1.2 to values higher than 1.5.[12]

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[11] The priors used for the Bayesian estimation are the same as the ones reported in Table 1A and Table 1B in Smets and Wouters (2007).

[12] Although similar, our estimates are not identical to the ones obtained by Smets and Wouters (2007). This, however, should not be a concern, as there are two important reasons for these minor discrepancies. First, we use different time windows for both subsamples. Second, since the original paper of Smets and Wouters (2007) was published, the official data used in the estimation has been revised. In Appendix B we document this discrepancy by focusing on the same sample as the one used by Smets and Wouters, which is from 1966:1 to 2004:4. Hence, even if a researcher were to replicate the exact same exercise as in the original paper using the currently available and revised data, she would obtain slightly different estimates. The data source, as well as the codes for replicating Smets and Wouters (2007) are available at https://www.aeaweb.org/articles?id=10.1257/aer.97.3.586.

One caveat of our procedure is that the Smets and Wouters (2007) estimation approach rules out indeterminate equilibria by construction. Lubik and Schorfheide (2004), however, estimate a small scale DSGE model and show that the equilibrium is indeterminate when monetary policy is passive, i.e. Taylor-rule inflation response is lower than 1. Our estimate of the Taylor-rule inflation response does not lie at the boundary of the parameter region (which is at the value equal to 1) imposed by this method. For future research it would be interesting to investigate whether allowing for indeterminacy changes significantly the estimated structure of the economy and the propagation of the shocks.[13]

Since the inflation response in the Taylor rule is the policy parameter that has changed the most, and since the literature agrees that this is in fact the key policy parameter, in the rest of the paper we will refer to monetary policy changes in terms of changes in this parameter.

Finally, the bottom panel of Table 1 reports the estimates of all the remaining parameters, labeled as structure parameters. Most of these parameters appear to be stable across the two subsamples. The notable exception are the parameters related to labor market conditions (wage markup and labor supply elasticity) and the adjustment cost parameters.

The estimation results conducted in the two subsamples provide an estimate of the changes in the macroeconomic environment between the pre- and post-1980. Given our notations from the previous section, they provide the estimates of the four sets of parameters, Φ, Θ, Ψ and Σ_ε, in the two subsamples. In the next section, we use these estimates to compute the sensitivity of macroeconomic variables to changes in monetary policy in the two subsamples.

4 Sensitivity of Macroeconomic Volatility to Monetary Policy

Using the parameter estimates from the previous section, here we first compute two measures of interest, the sensitivity to the changes in monetary policy, ϵ, and its elasticity, ϵ^L. Given the complexity of the analytical form of this model, we obtain these two measures by numerically computing the derivatives in equations (3) and (4) instead. We focus on two endogenous variables, namely inflation and output gap. As mentioned above, we only focus on the variations in one policy-rule parameter, a response to inflation in the Taylor rule, ϕ_π.[14] Hence, we measure sensitivity as a change in the volatility

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[13] To the best of our knowledge, methods that would allow for indeterminate equilibria when estimating a medium-scale DSGE model such as the one considered in this paper have not been developed. Several researchers (see Bianchi and Nicolò (2016), Farmer et al. (2015)) have recently worked on developing methods that would allow for indeterminacy in the estimation of DSGE models. However, because of the complexity of the issue, they have, so far, limited their attention to the canonical three-equation DSGE model.

[14] Our choice to focus only on the Taylor-rule parameter linked to inflation is motivated by two observations. First, the large majority of the literature documents a tighter response to inflation during the Volcker era, thus arguably pointing to that parameter as the indicator of a hawkish or dovish monetary policy stand. Second, the estimates reported in Table 2 show that the policy response to output gap was almost identical across the two subsamples.

of inflation and output gap that could be induced by a marginal change in ϕ_π.

Table 2 reports sensitivity and elasticity measures for both inflation and output gap variance. The sensitivity of inflation variance has drastically declined, from -5.2 in the first subsample to -0.2 in the second subsample. The negative signs are consistent with the theory that suggests that inflation volatility declines with a stronger response to inflation in the Taylor rule. Our contribution, however, is to compute and understand the magnitude of that decline, as well as its causes. Our measure of interest can be interpreted as the slope of inflation and output gap standard deviations with respect to ϕ_π; hence, the low number in the second subsample suggests a drastic decline in the ability of monetary policy to further smooth out the variance of inflation. Importantly, this result is not a mere consequence of the different levels of the variables involved in the definition of effectiveness (i.e. the variance of inflation and the value of the Taylor-rule parameter, ϕ_π), because also the elasticity of the effectiveness largely declined, from -5.6 in the first subsample to -2.2 in the second subsample. In other words, this finding implies that in the post-1980 period, a 1 percent increase in the monetary authority's response to inflation in the Taylor rule leads to only a 2.2 percent reduction in inflation variance. The same policy change in the pre-1980 period implied a much larger reduction, equal to 5.6 percent.

Regarding output gap, our results also suggest that the ability of monetary policy to stabilize output gap by changing ϕ_π is low and has roughly remained the same in the two subsamples. Therefore, in the next subsection we limit our analysis to implications for inflation.

Finally, notice that our results are robust to different specifications of the second subsample, i.e. the second subsample without Great Recession period (third column), as well as the second subsample with the inclusion of the 1980:1-1983:4 period (fourth column).

Table 2: SENSITIVITY AND ELASTICITY OF INFLATION AND OUTPUT GAP VOLATILITY TO MONETARY POLICY CHANGES

	Sample 1 1955-1979	Sample 2 (break) 1984-2012	Sample 2 (short) 1984-2007	Sample 2 (no break) 1980-2012
		Inflation		
Sensitivity, ϵ	-5.2	-0.2	-0.2	-0.2
Elasticity, ϵ^L	-5.6	-2.2	-1.8	-2.2
		Output Gap		
Sensitivity, ϵ	-0.2	-0.2	-0.1	-0.2
Elasticity, ϵ^L	-0.1	-0.4	-0.2	-0.4

Note: This table reports the sensitivity, ϵ, of inflation (top panel) and output gap (bottom panel), and the elasticity of this sensitivity measure, ϵ^L, over several time periods: the first subsample (1955:1-1979:4, first column), the second subsample with (1984:1-2012:1, second column) and without (1984:1-2007:1, third column) Great Recession period, and the second subsample with an earlier starting date (1980:1-2012:1, fourth column). The sensitivity is measured as the derivative of the standard deviation of the macroeconomic variable of interest with respect to a marginal change in the Taylor-rule parameter with inflation, ϕ_π. The elasticity measure eliminates any level effect. As displayed in equations (3) and (4), these two measures are functions of the structural parameters of the model, and, thus, will depend on their estimated values in these different time periods, as reported in Table 1.

4.1 Counterfactuals

What are the main differences between the two sample periods that weakened monetary policy's potential to stabilize inflation? The DSGE model described above allows us to answer this question by performing various counterfactual scenarios with the following idea. Since we estimate that the elasticity of inflation variance to changes in monetary policy dropped from -5.6 in the first subsample to -2.2 in the second subsample, the counterfactuals would uncover roles that different aspects of the economic environment played in this reduction.

Following a similar approach as Boivin and Giannoni (2006), we ask the following question. Had a subset of parameters remained at their pre-Volcker era values, what would the elasticity of inflation variance's sensitivity to a more aggressive monetary policy have been? Namely, updating only a subset of parameters to its second-subsample value, while keeping all the other parameters at their first-subsample values, would reveal the contribution of that particular subset to the estimated elasticity drop between the two subsamples. In particular, if the implied difference between the counterfactual and original elasticity is large so is the role of that particular subset of parameters. The estimated elasticities in the two subsamples are displayed in the top panel, and the four counterfactual elasticities brought about by a change in only one set of parameters at a time are displayed in the middle panel. The notations of the four counterfactuals are quite intuitive. For example, the notation *Policy* refers to the scenario where all the parameters of the model are kept at their pre-1980 estimates, except for the monetary policy parameter which is assumed to be at its post-1980 period estimate. We denote this counterfactual elasticity as $\epsilon^L(\Theta_1, \Phi_2, \Psi_1, \Sigma_{\varepsilon,1})$.

Table 3: Counterfactual Effectiveness Elasticity, ϵ^L

Sample 1: 1955-1979	$\epsilon^L(\Theta_1, \Phi_1, \Psi_1, \Sigma_{\varepsilon,1})$	-5.6
Sample 2: 1984-2012	$\epsilon^L(\Theta_2, \Phi_2, \Psi_2, \Sigma_{\varepsilon,2})$	-2.2
Single Change in Parameters		
Structure	$\epsilon^L(\Theta_2, \Phi_1, \Psi_1, \Sigma_{\varepsilon,1})$	-4.4
Variance Shocks	$\epsilon^L(\Theta_1, \Phi_1, \Psi_1, \Sigma_{\varepsilon,2})$	-6.0
Policy	$\epsilon^L(\Theta_1, \Phi_2, \Psi_1, \Sigma_{\varepsilon,1})$	-2.5
Persistence Shocks	$\epsilon^L(\Theta_1, \Phi_1, \Psi_2, \Sigma_{\varepsilon,1})$	-2.4
Cumulative Change in Parameters		
Structure	$\epsilon^L(\Theta_2, \Phi_1, \Psi_1, \Sigma_{\varepsilon,1})$	-4.4
Structure + Variance	$\epsilon^L(\Theta_2, \Phi_1, \Psi_1, \Sigma_{\varepsilon,2})$	-4.4
Structure + Variance+ Policy	$\epsilon^L(\Theta_2, \Phi_2, \Psi_1, \Sigma_{\varepsilon,2})$	-3.4
Structure + Variance+ Policy+ Persistence	$\epsilon^L(\Theta_2, \Phi_2, \Psi_2, \Sigma_{\varepsilon,2})$	-2.2

Note: The table reports the estimated elasticity of inflation variance sensitivity to monetary policy changes in the two subsamples (top panel) and in the various counterfactual scenarios (middle and bottom panels). In the middle panel, in each scenario we recompute the same statistic by keeping only one set of parameters at its first-subsample value and the remaining three sets of parameters at their second-subsample values. In the bottom panel, we update, one by one, the four sets of parameters to their second-subsample values and report cumulative counterfactual elasticity.

Two main results emerge. The main drivers of the reduced elasticity of the sensitivity of inflation variance to monetary policy changes are already more aggressive monetary policy with respect to the pre-1980 period (counterfactual scenario *Policy*), and changed persistence of the exogenous shocks (counterfactual scenario *Persistence Shocks*), as a single change in both sets of parameters leads to a counterfactual elasticity very close to the one estimated in the second subsample (-2.5 and -2.4, respectively). On the contrary, the scenario *Structure* suggests that an evolution of the structure parameters of the model alone, gathered in the vector Θ, would not have been able to explain the large decline in the sensitivity. A similar result holds for the variance of the shocks, as displayed by the scenario *Variance Shocks*.

Because the relationship between the elasticity of the sensitivity and the four different sets of parameters is highly non-linear, the four different scenarios above are not additive. Hence, another way to understand the contribution of each set of parameters is to decompose the estimated reduction, from -5.6 in the first to -2.2 in the second subsample, by cumulatively updating the four sets of parameters to their second-subsample values. The results of these counterfactuals are displayed in the bottom panel of Table 3. Let us start from the *Structure* scenario, $\epsilon^L(\Theta_1, \Phi_1, \Psi_1, \Sigma_{\varepsilon,1})$, as in the middle panel. As already pointed out, if the only parameters that changed were the structure parameters, the sensitivity would have declined only to -4.4. If, in addition to updating structure parameters we also updated the variance of the shocks, thus obtaining the scenario *Structure + Variance*, $\epsilon^L(\Theta_2, \Phi_1, \Psi_1, \Sigma_{\varepsilon,2})$, the sensitivity would not have been affected at all. This counterfactual scenario supports the conclusion that the change in the variance of the shocks could not have significantly affected the elasticity. Next, we also update the parameter of the Taylor rule to its second-subsample value, presented by the scenario *Structure + Variance+ Policy*, $\epsilon^L(\Theta_2, \Phi_2, \Psi_1, \Sigma_{\varepsilon,2})$. The counterfactual elasticity drops to -3.4, suggesting the importance of the policy parameter change in explaining the estimated elasticity decline. However, the final reduction in elasticity to the second-subsample value of -2.2, could have been explained only with the change in parameters related to the persistence of the shocks. These counterfactuals also suggest that, in addition to the more aggressive monetary policy, a change in the persistence of the shocks (or at least some shocks) was likely a main driver of the elasticity decline. Below we analyze this result even further by uncovering the role of each of the seven shocks.

4.2 Persistence of the Shocks

Because both sets of counterfactuals performed above undoubtedly point out to the changed persistence of the exogenous shocks as one of the main drivers of the decline in our elasticity measure, here we explore which shock(s) in particular lead to this decline.

We start from the observation that changed persistence of the shocks could explain the difference between the -2.2 elasticity in the second subsample where, by construction, persistence parameters of all seven shocks are at their second-subsample values, and the -3.4 elasticity in the counterfactual where persistence parameters of all seven shocks are reverted to their first-subsample values (*Structure+Variance+Policy*). To understand which of the seven shocks was responsible for this difference, we run seven counterfactual exercises. In each scenario, we revert persistence of one shock (denoted by

i) at a time at its pre-1980 value while keeping persistence parameters of the remaining six shocks, as well as other sets of parameters, at their post-1980 values. We denote these counterfactual scenarios as $\epsilon^L(\Theta_2, \Phi_2, \Psi_{-i,2}, \Psi_{i,1}, \Sigma_2)$.

These additional counterfactuals suggest that, among the seven shocks, the changed properties of the wage markup shock are crucial for explaining our results. As displayed in Table 4, elasticity is affected only when we revert persistence of the wage markup to its first-subsample value. In fact, if all the parameters of the model except for the persistence of the wage markup process were kept at their second sample values, our sensitivity measure would still be quite large, equal to -3.4. On the contrary, keeping the persistence of any other shock at its second sample value causes the elasticity to remain still low and close to the overall second-subsample value, equal to -2.2. This result suggest that the crucial persistence parameter behind the drop in elasticity was changed persistence of the markup shock.

Table 4: Persistence of the Shocks and the Elasticity

		Inflation
Sample 1: 1955-1979	$\epsilon^L(\Theta_1, \Phi_1, \Psi_1, \Sigma_1)$	-5.6
Sample 2: 1984-2012	$\epsilon^L(\Theta_2, \Phi_2, \Psi_2, \Sigma_2)$	-2.2
Counterfactual:		
Structure + Variance+ Policy	$\epsilon^L(\Theta_2, \Phi_2, \Psi_1, \Sigma_2)$	-3.4
	$\epsilon^L(\Theta_2, \Phi_2, \Psi_{-i,2}, \Psi_{i,1}, \Sigma_2,)$	
i=Technology		-2.2
i=Inv. Specific		-2.2
i=Risk Premium		-0.8
i=Gov't		-2.2
i=Wage Markup		-3.4
i=Price Markup		-2.8
i=Monetary		-2.2

Note: This table reports the estimated elasticity in the first sample 1955-1979 period (first row), in the second sample 1984-2012 period (second row), and in the counterfactual scenario in which all the parameters of the model are kept at the second-subsample values, except for the persistence of the shocks . The next seven rows report the results of seven counterfactual scenarios, where each counterfactual scenario recomputes the sensitivity by keeping the persistence of only one shock (denoted by i) at a time at its first sample period value while keeping all the other parameters, including the persistence of the remaining six shocks (denoted by $-i$), at their second sample period values.

In fact, recall from Table 1 that the persistence of the wage markup shock halved, decreasing from 0.99 in the first to 0.41 in the second subsample, while, at the same time, its standard deviation almost doubled, increasing from 0.20 in the first to 0.40 in the second subsample. Since these two changes have opposite effects on the unconditional variance of the wage markup process, it is not clear whether the contribution of this shock to the overall variance of endogenous variables has changed. More generally, one might wonder whether the changes in the exogenous processes, in the monetary policy, and in the structure of the economy also affected the contribution of different shocks to inflation dynamics. To investigate this issue, in Table 5 we report the variance decomposition of inflation in the two subsamples. We observe that the contribution of the wage markup shock to inflation variations is extremely large in the first subsample, amounting to around 75 percent. In the second subsample, however, the contribution of this shock sharply declined to about 10 percent. At the same time, the contributions of the risk premium shock and the price markup shock increased.[15]

Table 5: VARIANCE DECOMPOSITION OF INFLATION

	Inflation	
	Sample 1: 1955-1979	Sample 2: 1984-2012
	Supply Shocks	
Technology	5.3	4.6
Inv. Specific	0.8	0.2
	Demand Shocks	
Risk Premium	0.2	8.9
Gov't	0.3	0.5
	Markup Shocks	
Wage Markup	75.8	11.3
Price Markup	14.3	73.4
	Policy Shocks	
Monetary	2.6	0.8

Note: This table reports the estimated percentage contributions of seven shocks to the variance of inflation in the first sample 1955-1979 period (first column) and in the second sample 1984-2012 period (second column). The seven shocks are divided into four groups: supply shocks, demand shocks, markup shocks, and policy shocks.

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[15] The importance of the wage-markup shock in explaining inflation variance is a common finding in the literature. Even when adding unemployment as observable, as in Gali, Smets, and Wouters (2012), this shock still represents a large determinant of inflation.

5 Simple Model

In order to gain intuition for the results obtained above, here we investigate the relationship between the properties of the shock to the labor market and the effectiveness of monetary policy, using a simple three-equation New Keynesian model as in Galí (2009). In the previous sections we showed that the conditions on the labor market, manifested through changed properties of the wage markup shock, are responsible for the decrease in the sensitivity of inflation variance to changes in monetary policy. The purpose of the simple model is then to analyze how changes in the dynamics of this labor wedge, abstracting from any structural interpretation, can alter the effectiveness of monetary policy.

5.1 A Simple NK Model with Labor Shock

In addition to the monetary policy shock, v_t, and technology shock, a_t, we also introduce a shock d_t which operates directly as a labor market shock. Namely, we introduce a shock to labor in the instantaneous utility function given by,

$$u\left(C_t, N_t\right) = \frac{C_t^{1-\sigma}}{1-\sigma} - \exp^{d_t} \frac{N_t^{1+\phi}}{1+\phi},$$

where $d_t = \rho_d d_{t-1} + \varepsilon_{t,d}$. The presence of this shock affects the optimality condition that relates marginal rate of substitution between consumption and leisure with the real wage or marginal product of labor:

$$\exp^{d_t} \frac{N_t^{\phi}}{C_t^{-\sigma}} = \frac{W_t}{P_t}.$$

As discussed in Chari, Kehoe, and McGrattan (2007), this labor wedge can be interpreted in different ways, for example as fluctuations in the bargaining power of unions or as fluctuations in the value of the leisure of consumers.

After taking logs, the intratemporal and intertemporal optimality conditions are given by,

$$d_t + \phi n_t + \sigma c_t = w_t - p_t, \tag{6}$$

$$c_t = c_{t+1} - \frac{1}{\sigma}\left(i_t - E_t \pi_{t+1} - \rho\right), \tag{7}$$

where lowercase letters denote the natural logs of the corresponding variable. As evident in equation (6), the labor supply shock, d_t, affects the real wage dynamics in exactly the same way as the wage markup shock does in a fully specified DSGE model.

We interpret the output in the economy with monopolistic competition and flexible prices as the *natural* level of output, with the corresponding interest rate as the *natural* interest rate given by,

$$r_t^n = \rho + \sigma \frac{1+\phi}{\sigma(1-\alpha)+(\alpha+\phi)} E_t \Delta a_{t+1} - \sigma \frac{1-\alpha}{\sigma(1-\alpha)+(\alpha+\phi)} E_t \Delta d_{t+1}. \tag{8}$$

The difference with respect to the scenario without the labor market shock is the last term in (8), which clearly depends on the properties of the d_t process. When we also add price stickiness, we can compute the level of output gap as the deviation of the output in this economy from the natural level of output defined above. Let us denote $\frac{1-\alpha}{\sigma(1-\alpha)+(\alpha+\phi)} = \tilde{\psi}$ and $\frac{1+\phi}{\sigma(1-\alpha)+(\alpha+\phi)} = \psi_{ya}$. Then, output gap denoted as $\tilde{y} = y - y^n$, can be written as:

$$\tilde{y}_t = E_t \tilde{y}_{t+1} - \frac{1}{\sigma}(i_t - E_t \pi_{t+1} - \rho - \sigma \psi_{ya}(\rho_a - 1)a_t + \sigma \tilde{\psi}(\rho_d - 1)d_t), \tag{9}$$

where we assume that the shocks follow a first-order autoregressive process, i.e. $E_t \Delta a_{t+1} = (\rho_a - 1)a_t$ and $E_t \Delta d_{t+1} = (\rho_d - 1)d_t$. The solution of this simple model has the following form:

$$\begin{aligned} \tilde{y}_t &= \Lambda_{ya} a_t + \Lambda_{yd} d_t + \Lambda_{yv} v_t, \\ \pi_t &= \Lambda_{\pi a} a_t + \Lambda_{\pi d} d_t + \Lambda_{\pi v} v_t. \end{aligned}$$

Applying the method of undetermined coefficients, we can obtain the expressions for the reduced form equilibrium parameters, as reported in Appendix A.

Given this simple analytical form, it is straightforward to derive the variance of inflation. Since we assume that shocks are orthogonal, the implied variance of inflation is

$$\sigma_\pi^2 = \Lambda_{\pi a}^2 \frac{\sigma_a^2}{1-\rho_a^2} + \Lambda_{\pi d}^2 \frac{\sigma_a^2}{1-\rho_d^2} + \Lambda_{\pi v}^2 \frac{\sigma_v^2}{1-\rho_v^2}.$$

In order to visualize the relationship between the standard deviation of inflation, σ_π, persistence of the labor market shock, ρ_d, and the response of monetary policy to inflation, ϕ_π, we assign values to the parameters of the model following the calibration in Galí (2009). For simplicity, we assume that σ_a is equal to zero. This assumption is consistent with the estimated minimal role that technology shocks play in explaining inflation variability, as displayed in Table 5. We fix the standard deviation of the monetary shock, σ_v, to 0.03 and its persistence, ρ_v, to 0.5. Figure 1 displays the resulting standard deviation of inflation (in percent) as a function of the persistence of labor supply shock, ρ_d, and the monetary policy parameter ϕ_π.[16] As expected, a stronger response of the monetary policy to inflation

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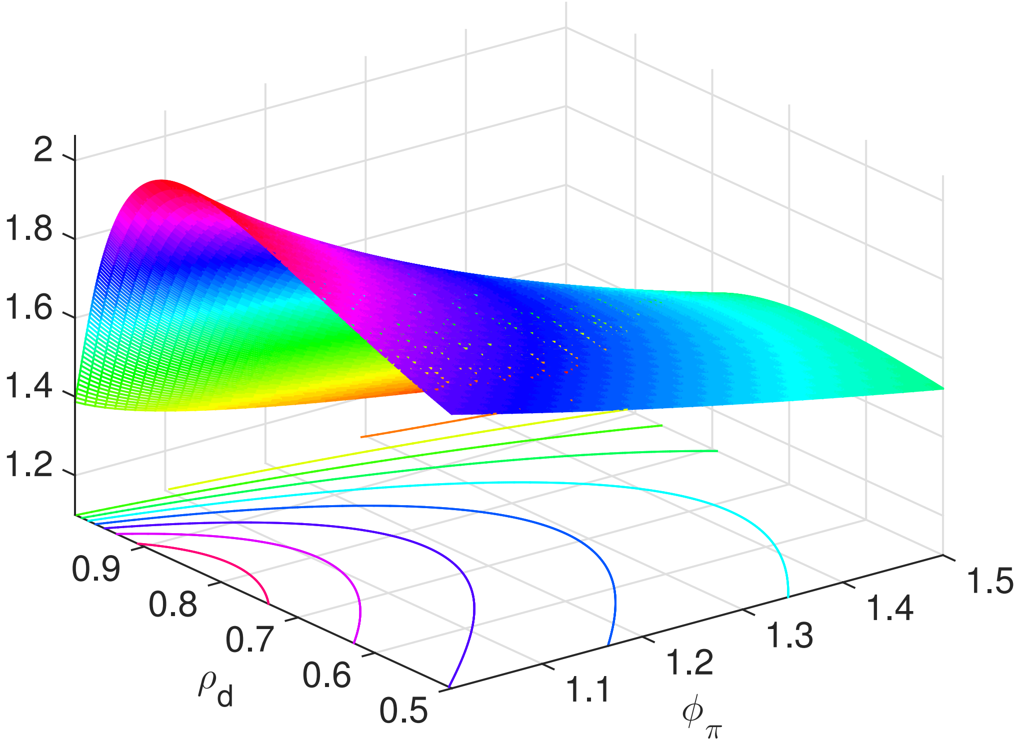
[16] In this figure, we fix the unconditional variance of the labor-supply process by adjusting the σ_d when ρ_d varies. Importantly, this non-monotonic relationship between σ_π, ρ_d, and ϕ_π is not an artefact of the simple model studied in

Figure 1: Standard Deviation of Inflation



Note: The figure displays the standard deviation of inflation, σ_π, as a function of the persistence of labor supply shock, ρ_d, and the monetary policy parameter ϕ_π. Persistence parameter takes the values $[0.5, 1]$, while the monetary policy parameter takes the values $[1, 1.5]$. The model considered is the New Keynesian model as in Galí (2009), augmented with the labor supply shock.

reduces inflation variance for any value of ρ_d. However, the slope of this reduction, which is the measure of the sensitivity of inflation variance to changes in monetary policy as introduced in Section 2, varies with ρ_d. This unequal decline stems from the non-monotone relationship between inflation variance and the persistence of the labor market shock. What drives this non-monotone relationship? In order to obtain intuition, assume that the only shock in the economy is the labor market shock. Recall that in this model the real effect of nominal rigidities comes from the assumption of the price adjustment a lá Calvo (1983). In each period, firms that are exogenously allowed to set their prices recognize that they might not have the same opportunity in the following periods. Therefore, they forecast future exogenous variables in order to calculate the expected marginal costs they will face in the future. Notice that marginal costs are related to the deviations of output from its natural level, or, equivalently, to the deviations of the real interest rate from its natural level. As equation (8) displays, if the exogenous labor market shock was the only shock in the economy and it was a random walk, then $E_t \Delta d_{t+1} = 0$,

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this section, since we can obtain a similar figure by numerically computing the relationship between σ_π, ρ_d, and ϕ_π that originate from the fully-fledged DSGE model as in Smets and Wouters (2007).

the natural rate of interest would be constant and, consequently, from equation (9), output gap would always be zero. In such a case, in fact, even firms that would be able to adjust their prices would choose not to update them, because the random walk nature of the exogenous process does not help in forming forecast for the evolution of its future realizations. As a result, the price would be always stable and nominal rigidities would not affect macroeconomic variables. This limit case helps to explain the declining values of the standard deviation of inflation for values of ρ_d close to unity, as displayed in Figure 1.[17] As the persistence parameter of the exogenous shock declines, the Calvo setting at first (with values of persistence close to 0.9) creates a large wedge between the optimizing and non-optimizing firms, thus increasing the standard deviation of inflation, but then, when the persistence of the process declines further, inflation variance starts to decline. The highly non-linear effects of changes in the forecastability of shocks can be visualized in the expressions for the reduced form equilibrium parameters, reported in Appendix A.

5.2 Sensitivity of Inflation Variance and its Elasticity

This simple but relevant setup allows us to analytically compute the sensitivity of inflation variance to changes in monetary policy, as well as the elasticity of this sensitivity. That is, we compute how much of the sensitivity (and its elasticity) is attributable to a specific shock, referring to it as the shock-specific sensitivity. For each of the shocks we compute by how much would the variance of inflation attributable to that particular shock change after a marginal increase in the monetary policy parameter, ϕ_π:

$$\epsilon_j = \frac{\partial \Lambda^2_{\pi,j}}{\partial \phi_\pi}, \text{ with } j = \{a, v, d\}. \tag{10}$$

After denoting

$$\Delta_j = (1 - \beta\rho_j)(\sigma(1 - \rho_j) + \phi_y) + \kappa(\phi_\pi - \rho_j), \text{ with } j = \{a, v, d\},$$

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[17] For the values of ρ_d close to one, the figure does not display zero inflation because the monetary shock in the model is not set to zero.

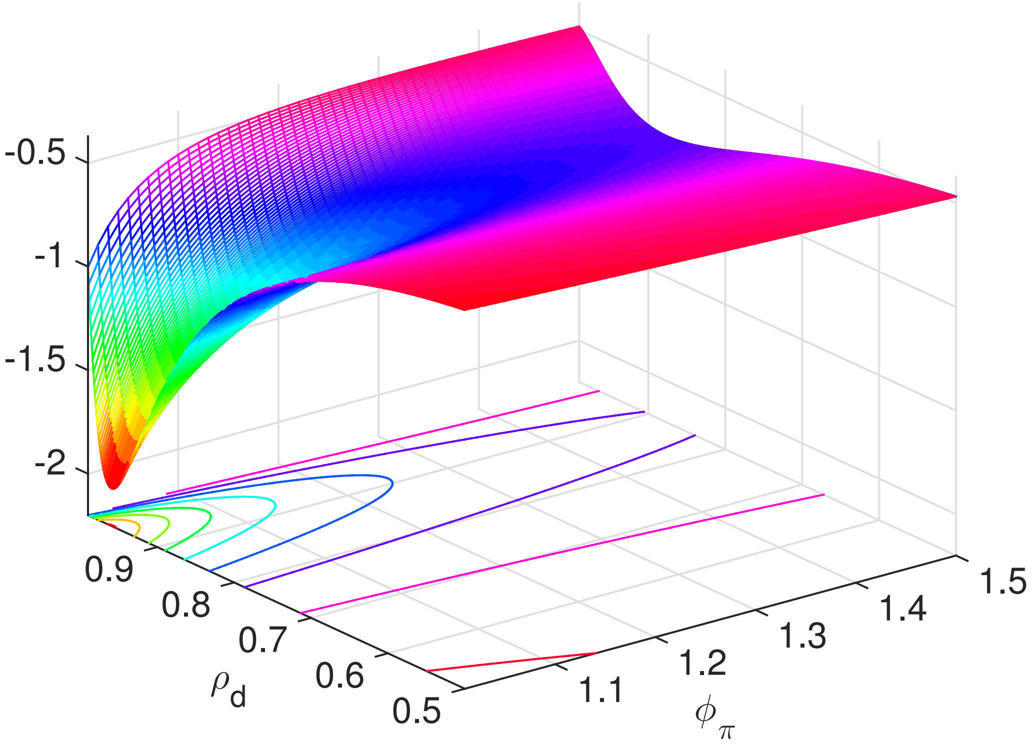
the analytical expressions for the shock-specific sensitivity can be written as:

$$\begin{aligned}\epsilon_v &= \frac{-2\kappa^2}{\Delta_v^3},\\ \epsilon_a &= \frac{-2\kappa\left(\sigma\psi_{ya}(1-\rho_a)\right)^2}{\Delta_a^3},\\ \epsilon_d &= \frac{-2\kappa^3\left(\sigma\tilde{\psi}(1-\rho_d)\right)^2}{\Delta_d^3}.\end{aligned}$$

Given the assumption of independent exogenous shocks, the total sensitivity is then simply given by

$$\epsilon = \sum_{j=\{a,v,d\}} \epsilon_j \frac{\sigma_j^2}{1-\rho_j^2}.$$

Figure 2: Elasticity of Inflation Sensitivity to monetary policy Changes



Note: The figure displays the elasticity of inflation variance sensitivity to changes in monetary policy as a function of the persistence of labor market shock, ρ_d, and the monetary policy parameter, ϕ_π. The model considered is the New Keynesian model as in Galí (2009), augmented with the labor market shock.

Notice that, given the simplicity of the model, we can obtain the elasticity of the effectiveness in its analytical form simply by computing

$$\epsilon_j^L = \epsilon_j \frac{\phi_\pi}{\sigma_\pi^2}, \text{ with } j = \{a, v, d\}.$$

We can then visualize the analytical relationship between the elasticity specific to the labor supply shock, ϵ_d^L, the response of monetary policy to inflation, ϕ_π, and the persistence of this shock, ρ_d. This relationship, as displayed in Figure 2, is highly non-monotone, implying that the sensitivity of inflation variance to changes in monetary policy is dependent on the value of the persistence of the labor supply shock. This sensitivity is the highest when the persistence of labor supply shock is high, and similar to the estimated value in our fully-fledged DSGE model.

6 Conclusion

Understanding the sources behind the fundamental changes experienced by the U.S. economy around the early 1980's, and reduction of macroeconomic volatility that followed, has occupied many researchers for a long time. More recently, some researchers recognized that also the patterns of comovements among output, hours and labor productivity changed after the early 1980s, attributing these changes to shifts in the composition of exogenous shocks or to structural changes on the labor market. Motivated by this evidence, in this paper we ask the following question: have these changes after the early 1980's affected the ability of monetary policy to smooth out aggregate fluctuations, and if so, through which channels?

In order to answer this question, we estimate a DSGE model in two subsamples, pre-1980 sample period (1955-1979) and post-1980 sample period (1984-2012), by using Bayesian techniques. We use a DSGE model because it allows for all the channels that could affect monetary policy's effectiveness, such as the structure of the economy, the relative importance of exogenous shocks, as well as their propagation, while being agnostic about their relative importance.

The estimated model reveals that the *sensitivity* of output gap volatility to systematic responses to inflation in the Taylor rule was low and has remained roughly unchanged across the two subsamples, while the *sensitivity* of inflation variance has drastically declined, from -5.2 in the first subsample to -0.2 in the second subsample. The corresponding *elasticity* has also largely declined, from -5.6 in the first subsample to -2.2 in the second subsample. This result has the following interpretation: a 1 percent increase in the magnitude of the response to inflation in the Taylor rule leads to a 5.6 percent decline in inflation variance in an economy that mimics the pre-1980 economy, and only to a 2.2 percent decline in an economy that mimics the post-1980 economy.

In the context of the Great Moderation literature, our results suggest that "good luck" amplified the effects of "good policy". In other words, while the pre-1980 economic environment was favorable for a systematic change in the conduct of monetary policy to induce a large reduction in inflation volatility, the post-1980 economic environment saw an inflation volatility much less responsive to any *further* monetary policy adjustments. A lesson to learn from this paper is, then, that if the economy were to be hit by some large unexpected shocks, the stabilization effect of monetary policy interventions through conventional Taylor-rule parameter manipulations might be weaker than in the past.

After investigating all the factors that could have explained this result, we showed that the behavior of the wage markup shock after early 1980's played a crucial role. In particular, unlike with all the other shocks in the model, variance of this shock doubled and its persistence decreased in the second subsample. Therefore, we showed that the changed behavior of the labor market has played the most important role in driving down potential effectiveness of monetary policy. This finding can be linked to the one in Chari, Kehoe, and McGrattan (2007), who recognize the importance of labor market wedges in explaining macroeconomic dynamics.

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A Appendix: Analytical Solution of the Model

Using the method of undetermined coefficients, it is straightforward to derive the coefficients of the analytical solution of the Simple Model in Section 5. They are as follows:

$$
\begin{aligned}
\Lambda_{yv} &= -\frac{1-\beta\rho_v}{(1-\beta\rho_v)(\sigma(1-\rho_v)+\phi_y)+\kappa(\phi_\pi-\rho_v)};\\
\Lambda_{\pi v} &= -\frac{\kappa}{(1-\beta\rho_v)(\sigma(1-\rho_v)+\phi_y)+\kappa(\phi_\pi-\rho_v)};\\
\Lambda_{ya} &= -\frac{\sigma\psi_{ya}(1-\rho_a)(1-\beta\rho_a)}{(1-\beta\rho_a)(\sigma(1-\rho_a)+\phi_y)+\kappa(\phi_\pi-\rho_a)};\\
\Lambda_{\pi a} &= -\frac{\kappa\sigma\psi_{ya}(1-\rho_a)}{(1-\beta\rho_a)(\sigma(1-\rho_a)+\phi_y)+\kappa(\phi_\pi-\rho_a)};\\
\Lambda_{yd} &= \frac{\sigma\tilde{\psi}(1-\rho_d)(1-\beta\rho_d)}{(1-\beta\rho_d)(\sigma(1-\rho_d)+\phi_y)+\kappa(\phi_\pi-\rho_d)};\\
\Lambda_{\pi d} &= \frac{\kappa\sigma\tilde{\psi}(1-\rho_d)}{(1-\beta\rho_d))(\sigma(1-\rho_d)+\phi_y)+\kappa(\phi_\pi-\rho_d)}.
\end{aligned}
$$

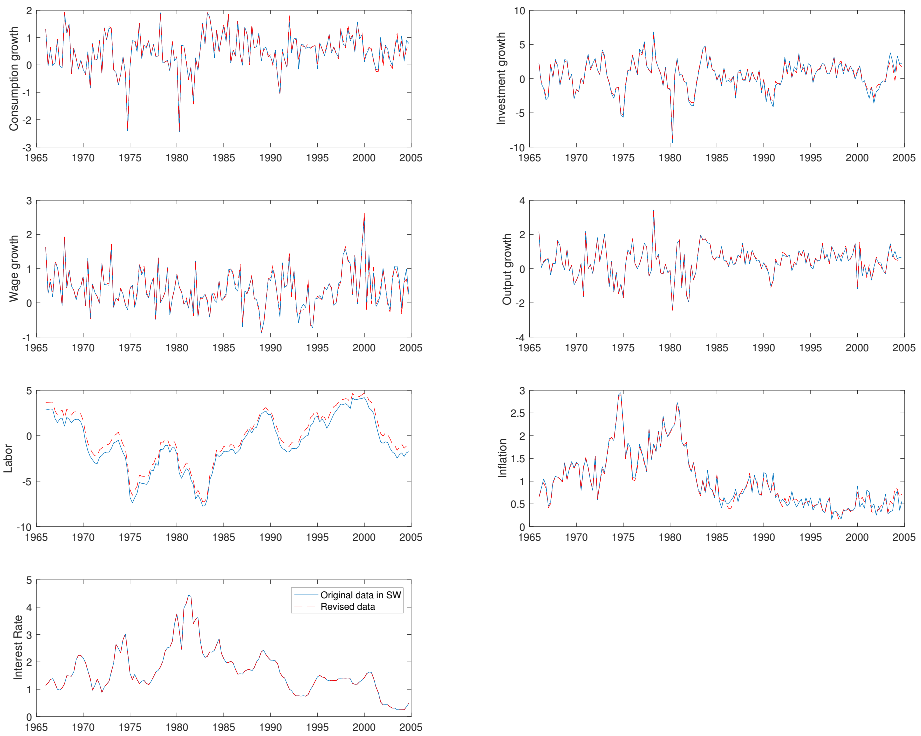
B Appendix: Revision of the Data

Table B1: Discrepancy between the original and revised data

	Original Data		Revised Data	
	Mean	Std.Dev	Mean	Std.Dev
Consumption Growth	0.492	0.685	0.500	0.691
Investment Growth	0.457	2.256	0.498	2.005
Wage Growth	0.410	0.564	0.415	0.570
Output Growth	0.408	0.855	0.421	0.851
Labor	-0.811	2.909	-0.132	2.900
Inflation	1.006	0.615	1.002	0.602
Interest Rate	1.664	0.830	1.664	0.830

Note: This table reports the estimated percentage contribution of seven shocks to the variance of inflation in the first sample 1955-1979 period (first column) and in the second sample 1984-2012 period (second column). The seven shocks are divided into four groups: supply shocks, demand shocks, markup shocks, and policy shocks.

Figure B1: Data used in the estimation: Original and Revised



Note: This figure displays the discrepancy between the original data used by in Smets and Wouters (2007) and their revised counterpart. The original data and the details of their construction are available at https://www.aeaweb.org/articles?id=10.1257/aer.97.3.586.