



**Discussion Paper No.18**

## **Vector Autoregression Analysis and the Great Moderation**

**by Luca Benati and Paolo Surico**

# External MPC Unit Discussion Paper No. 18

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October 2007

ISSN: 1748 – 6203  
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The authors wish to thank Fabio Canova, Tim Cogley, Giancarlo Corsetti, Mark Gertler, Marc Giannoni, Christian Julliard, Thomas Lubik, Giorgio Primiceri, Juan Rubio-Ramirez, Federico Ravenna, Frank Schorfheide, Andrew Scott, Andrew Sentance, Ida Wolden Bache, Tao Zha and an anonymous referee for helpful discussions, and seminar participants at the Federal Reserve Bank of New York, the Federal Reserve Bank of Richmond, the Board of Governors of the Federal Reserve System, the Universitat Autònoma de Barcelona, the London School of Economics and Political Science, the Bank of Spain, the 2006 meetings of the Royal Economic Society and the Society for Computational Economics, the 5th Workshop on Macroeconomics Dynamics held at the Bank of Italy and the 2nd Oslo Workshop on Monetary Policy for comments. This paper is best viewed in colour. Part of this work was done while the first author was visiting the Directorate General Research of the European Central Bank, whose kind hospitality is gratefully acknowledged.

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## **Abstract**

Most analyses of the U.S. Great Moderation have been based on VAR methods, and have consistently pointed toward good luck as the main explanation for the greater macroeconomic stability of recent years. Using data generated by a New-Keynesian model in which the only source of change is the move from passive to active monetary policy, we show that VARs may misinterpret good policy for good luck. In particular, we detect significant breaks in estimated VAR innovation variances, although in the data generating process the volatilities of the structural shocks are constant across policy regimes. Counterfactual simulations, structural and reduced-form, point toward the incorrect conclusion of good luck. Our results cast doubts on the existing notion that VAR evidence is inconsistent with the good policy explanation of the Great Moderation.

Key words: Great inflation, passive policy, break tests, vector autoregressions.

JEL classification: E38, E52.

## Summary

Post-WWII U.S. economic history is usually divided into two distinct periods. The first period, which extends up to the end of the Volcker disinflation around the mid-1980s, is characterised by macroeconomic turbulence, with highly volatile output growth, and highly volatile and persistent inflation. The most recent period, from the end of the Volcker disinflation to the present day, is marked, in contrast, by significantly smaller volatilities of both inflation and output growth and, possibly, by a lower extent of inflation persistence. These dramatic changes in the reduced-form properties of the U.S. economy over the last several decades are known as the ‘Great Moderation’.

A vast empirical literature has investigated the source(s) of the Great Moderation in an attempt to disentangle the relative contributions of two main explanations: good policy and good luck. The good luck hypothesis has been advocated by studies based on Vector AutoRegression (VAR) methods. The good policy hypothesis has been, in contrast, advocated by studies based on estimated sticky-price models in which monetary policy is allowed to switch from passive (i.e. weakly reactive to inflation) to active (i.e. strongly reactive to inflation).

This paper tries to reconcile the conflicting results of the two strands of the literature by asking whether the differences in the methods between the two approaches can account for the differences in the results. To investigate the ability of VARs to identify the sources of the Great Moderation, we use as data generation process a standard sticky-price New Keynesian model in which the *only* source of change is the move from passive to active monetary policy.

We simulate the model under both policy regimes and apply widely used reduced-form and structural estimation techniques on the simulated data. Can VAR methods uncover the good policy explanation that we have constructed? The answer is ‘No’. In particular, we find that: (i) estimated VAR innovation variances exhibit large and significant instability across policy regimes, even in the absence, by construction, of any change in the volatilities of the structural shocks in the data generating process. VAR coefficients, on the other hand, exhibit significant instability only in the interest rate equation; (ii) counterfactual simulations —both structural and reduced-form— strongly point towards the incorrect conclusion that monetary policy played no role.

It is worth emphasising that earlier contributions have concluded that good luck has been the

driving force of the Great Moderation on the basis of this kind of findings. Results very similar to those obtained on actual data are produced, in this paper, within a framework in which the change in macroeconomic dynamics is driven *exclusively* by improved monetary policy.

We identify two main dimensions along which VAR results can be misleading. First, changes in the monetary policy rule of the *structural model* have an impact on both the covariance matrix and the coefficients of the VAR representation of the structural model. In particular, the impact of the policy shift on the VAR covariance matrix *can* dominate the impact on the VAR coefficients. Previous literature, however, has routinely interpreted changes in the volatilities of the VAR innovations as evidence against good policy and in favour of good luck. Second, changes in the interest rate equation of a *structural VAR* bear no clear-cut relationship with changes in the parameters of the monetary policy rule of the underlying structural model. Earlier contributions, in contrast, have performed counterfactual simulations in structural VARs under the presumption that switching the estimated coefficients of the interest rate equations provides a reasonable approximation to switching the parameters of the monetary policy rule in the underlying structural model.

## 1 Introduction

Post-WWII U.S. economic history is usually divided into two distinct periods. The first period, which extends up to the end of the Volcker disinflation around the mid-1980s, is characterised by macroeconomic turbulence, with highly volatile output growth, and highly volatile and persistent inflation. The most recent period, from the end of the Volcker disinflation to the present day, is marked, in contrast, by significantly smaller volatilities of both inflation and output growth and, possibly, by a lower extent of inflation persistence.<sup>(1)</sup> These dramatic changes in the reduced-form properties of the U.S. economy over the last several decades are known as the ‘Great Moderation’.<sup>(2)</sup>

A vast empirical literature has investigated the source(s) of the Great Moderation in an attempt to disentangle the relative contributions of two main explanations: good policy and good luck. Based on (time-varying) structural VAR methods, the good luck hypothesis has been advocated by a number of authors including Stock and Watson (2002), Primiceri (2005), Canova and Gambetti (2005), Gambetti, Pappa, and Canova (2006) and Sims and Zha (2006) for the U.S., and Benati (2007) for the U.K.. Based on an estimated sticky-price model of the U.S. economy, Lubik and Schorfheide (2004) find, in contrast, support for the good policy explanation advocated by Clarida, Gali, and Gertler (2000), according to which a shift in the systematic component of monetary policy has been the driving force behind the recent macroeconomic stability.

This paper tries to reconcile the conflicting results of the two strands of the literature by asking whether the differences in the methods between the two approaches can account for the differences in the results. To investigate the ability of VARs to identify the sources of the Great Moderation, we use as data generation process a standard sticky-price New Keynesian model in which the *only* source of change is the move from passive to active monetary policy.<sup>(3)</sup>

We simulate the model under both policy regimes and apply widely used reduced-form and structural estimation techniques on the simulated data. Can VAR methods uncover the good policy explanation that we have constructed? The answer is ‘No’. In particular, we find that:

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(1) The decline in inflation persistence is still a contentious issue in empirical macroeconomics—see eg Kim, Nelson, and Piger (2004), Cogley and Sargent (2002) and Cogley and Sargent (2005), on the one hand, and Stock (2002) for an opposite point of view.

(2) See Kim and Nelson (1999) and McConnell and Perez-Quiros (2000).

(3) As we abstract from the role of fiscal policy, the relationship between the monetary policy stance and equilibrium (in)determinacy in a plain New-Keynesian model is one-to-one, with a passive (active) rule associated with an indeterminate (determinate) equilibrium. As shown by Leeper (1991), in more complex settings this is not the case.

- Based on bootstrapped critical values, estimated VAR innovation variances exhibit large and significant instability across policy regimes, even in the absence, by construction, of any change in the volatilities of the structural shocks in the data generating process. VAR coefficients, on the other hand, exhibit significant instability only in the interest rate equation.
- Counterfactual simulations —both structural and reduced-form— strongly point towards the incorrect conclusion that monetary policy played no role.

It is worth emphasising that earlier contributions have concluded that good luck has been the driving force of the Great Moderation on the basis of this kind of findings. Results very similar to those obtained on actual data are produced, in this paper, within a framework in which the change in macroeconomic dynamics is driven *exclusively* by improved monetary policy.

We identify two main dimensions along which VAR results can be misleading. First, changes in the monetary policy rule of the DSGE model have an impact on both the covariance matrix and the coefficients of the VAR representation of the model. In particular, the impact of the policy shift on the VAR covariance matrix *can* dominate the impact on the VAR coefficients. Previous literature, however, has routinely interpreted changes in the volatilities of the VAR innovations as evidence against good policy and in favour of good luck. Second, changes in the interest rate equation of a structural VAR bear no clear-cut relationship with changes in the parameters of the monetary policy rule of the underlying DSGE model. Earlier contributions, in contrast, have performed counterfactual simulations in structural VARs under the presumption that switching the estimated coefficients of the interest rate equations provides a reasonable approximation to switching the parameters of the monetary policy rule in the underlying DSGE model.

The paper is organized as follows. Section 2 compares, for the United Kingdom, the results from Bayesian time-varying parameter structural VARs with results coming from a more traditional ‘narrative-historical’ approach. The U.K. experience is particularly interesting here because, different from the U.S., narrative evidence strongly suggest that improved monetary policy played a significant role in fostering the recent macroeconomic stability, whereas the VAR evidence strongly supports the notion of a more favourable macroeconomic environment in the form of smaller shocks. Section 3 outlines the strategy of our experiment, briefly describes the standard New Keynesian sticky-price model and then motivates our focus on the position of Clarida, Gali, and Gertler (2000). Section 4 presents results based on reduced-form methods. In Section 5, we estimate structural VARs based on the simulated data, identifying the structural shocks via the sign



restrictions implied by the New Keynesian model. In Section 6, we investigate some of the reasons why structural VAR methods have difficulty uncovering the true source of changes in the data generating process. Section 7 concludes.

## 2 The U.K. experience

The literature on the Great Moderation has been dominated, so far, by a strictly econometric approach based on either reduced-form techniques, as in Ahmed, Levin, and Wilson (2004), or on structural methods, as in Primiceri (2005), Gambetti, Pappa, and Canova (2006) and Sims and Zha (2006). But econometric evidence is not the only kind of evidence we can rely on.

Historical and ‘narrative’ evidence, which for instance details the evolution of the intellectual climate surrounding monetary policymaking, may provide useful insights into the relative merits of ‘good luck’ and ‘good policy’ as the driving force of the recent macroeconomic stability.<sup>(4)</sup> While for the United States narrative accounts of the Great Inflation and the subsequent stabilisation do not seem to provide decisive evidence in favour of either hypothesis —see for instance DeLong (1997)—, evidence for the United Kingdom is strong.

### 2.1 From ‘inflation as a nonmonetary phenomenon’ to the Monetary Policy Committee

In their extensive analysis of the broad intellectual climate surrounding monetary policymaking in the United Kingdom during the 1960s and 1970s, Nelson and Nikolov (2004) point out that

*[m]onetary policy was not seen as essential for inflation control; the latter, instead, was largely delegated to incomes policy (wage and price controls). [...] Essentially, UK policymakers viewed monetary policy as disconnected from inflation for two reasons. First, inflation was perceived as largely driven by factors other than the output gap; secondly, policymakers were highly sceptical about the ability of monetary policy to affect aggregate demand or the output gap appreciably. [This] led to a combination of easy monetary policy and attempts to control inflation through other devices, and contributed heavily to the breakout of inflation in the 1960s and 1970s.*  
(emphasis added)

Similar views have been expressed by the Governor of the *Bank of England*, Mervyn King, in his reflections on the evolution of macroeconomic thinking and monetary policymaking in the United

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(4) For more technically oriented readers, who may be tempted to dismiss such arguments, it is worth noting that *Monetary History* by Friedman and Schwartz was *entirely* based on the narrative approach and that it has been one of the most influential macroeconomic books of the XX century. For a more recent example of such an approach, see Romer and Romer (2002).

Kingdom since the 1960s —see King (2005).

From the end of the second world war until the mid to late 1970s, the majority view of [U.K.] academic economists and policy-makers alike was that monetary policy had rather little to do with inflation, and was largely ineffective as an instrument of demand management. [...] Fortunately, the theory and practice of monetary policy in the UK have changed out of all recognition in the past twenty-five years.

These assessments can be supported by those involved at policy over the time. For example, Nicholas Kaldor (1971), then adviser to Harold Wilson, stated that

[i]t is also far more generally acknowledged—even by Conservative Prime Ministers—that the process of inflation is cost-induced and not demand-induced, with the evident implication that it can be tackled only by an incomes policy.<sup>(5)</sup>

Along similar lines, Alec Cairncross (1996), who served as a Treasury official<sup>(6)</sup> during that period, provides a view consistent with the position of Nelson and Nikolov (2004) and King (2005):

[i]n the effort to limit inflation there was little thought of reliance on monetary policy, much less *exclusive* reliance on monetary policy [...]. The prevailing view was that of the Radcliffe Committee [...]: monetary policy itself had limited usefulness in controlling inflation. [...] Even after the IMF seminar in 1968, the Treasury remained sceptical [...] of the influence of monetary policy on the rate of inflation, *and was anxious to keep rates as low as possible in the interests of holding down interest on government debt and encouraging fixed investment.*<sup>(7)</sup> (emphasis added)

The intellectual foundation of this position was the Report of the Radcliffe Commission (1959), the *manifesto* of post-WWII U.K. Keynesianism. In the words of Batini and Nelson (2005)

[...] *the Report's view of the transmission mechanism was inconsistent with assigning any important macroeconomic role for monetary policy*, not just a framework that emphasises monetary aggregates. Thus the implication of its analysis was not a preference for a Wicksellian analysis of price-level determination over a quantity-oriented approach, but a rejection of both these perspectives *due to its conclusion that aggregate demand (let alone the price level) was out of reach of monetary policy actions.* (emphasis added)

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(5) As quoted by King (2005).

(6) Until May 1997, U.K. monetary policy had been formulated by the Treasury. For a brief history of U.K. monetary arrangements, see Benati (2006, section 2).

(7) As quoted by Nelson and Nikolov (2004).

The Radcliffe Report conclusion was that ‘there can be no reliance on [interest rate policy] as a major short-term stabiliser of demand’. This position was reflected in several statements by U.K. policymakers of the 1960s and 1970s quoted by Nelson and Nikolov (2004) and Batini and Nelson (2005). The former, for example, quote Edward Heath, Prime Minister between 1970 and 1974, as rejecting *tout court* any notion of a link between money growth—in the specific case, M1—and inflation.

Over the last several decades, however, the United Kingdom has moved from a situation in which monetary policy was regarded as *unsuited* to controlling inflation, to one in which, on the contrary, it is regarded as *the crucial instrument*. Moreover, the change in the overall intellectual attitude towards inflation and monetary policy has been enshrined in the U.K. monetary framework with the introduction of inflation targeting in October 1992, the independence of the *Bank of England* and the creation of the *Monetary Policy Committee* in May 1997.

## **2.2 Results from time-varying parameters structural VARs**

The dramatic changes in both macroeconomic thinking and monetary policymaking since the beginning of the 1960s suggest that econometric analyses of the U.K. post-WWII period should point towards good policy as the main explanation of the Great Moderation. In fact, this is not the case. Benati (2007) fits a Bayesian time-varying parameters structural VAR with stochastic volatility to U.K. GDP growth, GDP deflator inflation, money growth, and a short-term rate. Consistent with the findings of Stock and Watson (2002), Primiceri (2005), Gambetti, Pappa, and Canova (2006) and Sims and Zha (2006) for the United States, his results strongly point towards good luck as the driving force of the recent macroeconomic stability in the United Kingdom, with only a minimal role played by improved monetary policy.

In principle, it is possible to entertain the position that changing in macroeconomic thinking and changing in macroeconomic dynamics has just been a *lucky* coincidence. On the basis of the narrative evidence available for the U.K., however, we find it hard to believe that the improvements in monetary policy making played no role at all in fostering macroeconomic stability. The inconsistency between narrative and empirical evidence poses a serious challenge for the ability of VAR methods to assess the relative merits of the good luck and good policy explanations of the Great Moderation.

### 3 Assessing VAR studies of the Great Moderation

Our goal is to assess the ability of VAR analyses to determine the role that monetary policy played in a specific historical episode, the Great Moderation. To this end, we design the following experiment:

*Suppose that the Great Moderation in the United States, for instance, was due exclusively to monetary policy, with a passive policy regime in place before October 1979 and an active policy regime in place after. Would (structural) VARs be capable of uncovering the data generating process?*

As we will see, the answer is ‘No’. When applied to a data generation process (henceforth, DGP) which, by construction, switches from passive to active monetary policy, structural VAR methods strongly point towards good luck as the explanation for the changes in the DGP.

#### 3.1 A model for monetary policy analysis

We use the standard New Keynesian sticky-price model surveyed by Clarida, Gali, and Gertler (1999) and Woodford (2003). In spite of its ‘bare bones’ structure, there are several reasons for preferring this model to more sophisticated ones (e.g., Smets and Wouters (2007) or Christiano, Eichenbaum, and Evans (2005)). In particular, its simplicity allows us to highlight the conceptual issues involved in the present exercise, without the unnecessary complications of more complex structures. Such a simplicity makes it possible to obtain analytical solutions under both policy regimes. This is particularly important for the case of passive policy, as it eliminates the need to resort to the approximated numerical solution described in Lubik and Schorfheide (2004).<sup>(8)</sup>

The model is given by

$$x_t = x_{t+1|t} - \tau(R_t - \pi_{t+1|t}) + g_t \quad (1)$$

$$\pi_t = \beta\pi_{t+1|t} + \kappa x_t + u_t \quad (2)$$

$$R_t = \rho_R R_{t-1} + (1 - \rho_R)[\phi_\pi \pi_t + \phi_x x_t] + \epsilon_{R,t} \quad (3)$$

$$g_t = \rho_g g_{t-1} + \epsilon_{g,t} \quad \text{and} \quad u_t = \rho_z u_{t-1} + \epsilon_{z,t} \quad (4)$$

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(8) Under the passive policy regime, we follow Lubik and Schorfheide (2003 and 2004) and we solve the model under the assumption that the impulse-response functions do not change discontinuously at the boundary between active and passive regions. This solution is labelled continuity.

where  $x_t$ ,  $\pi_t$ ,  $R_t$ ,  $g_t$ , and  $u_t$  are the output gap, inflation, the interest rate, a demand disturbance, and a cost push shock. The output gap is defined as the difference between output and the level consistent with flexible prices. All variables are expressed as log-deviations from a non-stochastic steady-state.

With a few exceptions discussed below, our calibration of the parameters of the model closely follows Clarida, Gali, and Gertler (2000). Specifically, we set  $\beta = 0.99$ ,  $\kappa = 0.3$ , and  $\tau = 1$ . The parameters of the monetary policy rule are the ‘baseline estimates’ reported in Table II of Clarida, Gali, and Gertler (2000):  $\phi_\pi = 2.15$ ,  $\phi_x = 0.93$ , and  $\rho_R = 0.79$  for the active regime, and  $\phi_\pi = 0.83$ ,  $\phi_x = 0.1$ , and  $\rho_R = 0.68$  for the passive regime.<sup>(9)</sup> As Clarida, Gali, and Gertler (2000) do not report estimates for the remaining structural parameters, we set  $\rho_g = \rho_u = 0.9$ , and the standard deviations of the structural shocks to  $\sigma_g = \sigma_u = 1$ , and  $\sigma_R = 0.25$ . Together with the structural parameters, the passive (active) policy implies indeterminacy (determinacy) in the former (latter) regime. In order to make our results as transparent as possible, under the passive regime we set the variance of sunspot shocks to zero.

### 3.2 Modelling the policy shift

In the controlled experiment, we design a decline in macroeconomic volatilities that is driven *exclusively* by a change in the *systematic* component of monetary policy. In contrast, the standard deviations of the structural innovations, including the policy shocks, are kept constant across regimes. In the jargon of the literature on the Great Moderation, we are thus constructing a world of ‘bad policy’ before October 1979, and ‘good policy’ after 1982.<sup>(10)</sup> The question we then ask is: are VAR methods capable of uncovering the ‘truth’ that we have constructed?

Our focus on the policy regime shift advocated by Clarida, Gali, and Gertler (2000) and Lubik and Schorfheide (2004) is motivated by two main considerations. First, the dichotomy active-passive policy allows a researcher to *define* the notion of ‘bad policy’ in a precise and meaningful way. Within the active policy region, in fact, the modelling choice is limited, at the very best, between good policy and slightly better policy. Second, as we will show in Section 4, the move from

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(9) According to Table II in Clarida, Gali, and Gertler (2000), under the passive regime the parameter  $\phi_x$  should in fact be 0.27. This is the only departure from their ‘baseline estimates’. Setting  $\phi_x$  in the passive regime to the value in Clarida, Gali, and Gertler (2000) implies that the impact of a cost-push shock on the output gap would have different signs under the two regimes, and therefore it would create an obvious problem for the implementation of the sign restrictions method in Section 5. The problem disappears, however, setting  $\phi_x = 0.1$  in the passive regime.

(10) As for the UK, Benati (2006) dates the break in inflation and output dynamics around 1992. For an assessment of the UK macroeconomic policy and economic performance from the 1950s up to the mid-1990s see Sentance (1998).

passive to active policy *can* indeed generate a sizable fall in macroeconomic volatility such as to replicate the key qualitative features of the Great Moderation.<sup>(11)</sup>

We present estimates based on 10,000 simulations of the model under both the active and passive policy regimes. The only exception is represented by the tests for structural breaks at unknown points in the sample for both the VAR innovation variances and the coefficients of the VAR equations, which being based on bootstrapped critical values are computationally very intensive. In this case, and only in this case, results are based on 1,000 simulations and, for each simulation, the number of bootstrap replications is also set to 1,000. The sample length is set to  $T = 100$  under both regimes.<sup>(12)</sup>

#### 4 Reduced-form evidence

Instability of estimated innovation variances in (Markov-switching or time-varying parameters) VARs has been interpreted, so far, as strong evidence in favour of good luck and against good policy. In this section, we investigate the extent to which this interpretation is warranted. For the two policy regimes, the Panel (a) of Figure 1 plots the distributions of the estimated VAR total prediction variances while panels (b) to (d) plot the distributions of the estimated volatilities of the reduced-form innovations to the three VAR equations.<sup>(13)</sup>

In spite of the fact that the volatilities of the structural innovations are kept constant in the DSGE model, both the total prediction variance and the volatilities of the innovations to the inflation and output gap equations in the VAR exhibit a remarkable instability across policy regimes. The evidence for the interest rate equation is weaker, although it is still apparent. A significant decline in estimated VAR innovation variances is compatible with the notion that, under the earlier regime, a series of relatively large shocks hit the economy whereas, during the latter regime, the macroeconomic environment became more benign. Although such interpretation is standard in the literature, our simple example shows that also a shift from passive to active policy can replicate the instability of estimated innovation variances typically found in VAR analyses.

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(11) If policy shifts are modelled as stochastic, Davig and Leeper (2007), and Farmer, Waggoner, and Zha (2006) show that the mapping between policy activism and equilibrium determinacy becomes more complex. Interestingly, however, a move from passive to active policy is still capable of replicating the Great Moderation in their settings.

(12) In order to reduce as much as possible dependence from the initial conditions, we run a 100 periods long ‘pre-simulation’, which we then discard.

(13) The total prediction variance of a VAR is a simple measure of the total amount of noise hitting the system at each point in time, and it is defined as  $\ln[\det(V)]$ , where  $V$  is the covariance matrix of the VAR innovations. The lag orders of the VARs have been selected via the AIC.

As changes in the distributions of the estimated innovation variances to the inflation and output gap equations are large, formal tests should point towards statistical breaks. The first two columns of Table 1 report, for each of the three equations of the VAR, the medians of the bootstrapped  $p$ -values distributions of a Wald test for a single break across regimes in either the innovation variance, or the coefficients of the equation. The table also displays the 5th and 95th percentiles of the bootstrapped distributions.<sup>(14)</sup> Consistent with the finding of Figure 1, evidence of breaks in the innovation variance is very strong for both inflation and the output gap, while it is weak for the interest rate. Interestingly, results for the equation coefficients are exactly the opposite, with strong evidence of breaks in the interest rate equation, and very weak evidence of breaks in the other two equations.

It is worth emphasising that earlier contributions have found, on actual data, results that are qualitatively very similar to the results, on simulated data, shown in Table 1. Sims and Zha (2006), for instance, report that ‘the best fit [of the VAR] is with a version that allows time variation in structural disturbance variances only. Among versions that allow for changes in equation coefficients also, the best fit is for a one that allows coefficients to change only in the monetary policy rule.’ While earlier contributions have interpreted these results as evidence in favour of the good luck hypothesis, the instability of VAR innovation variances presented in Table 1 has been obtained within a framework in which improved monetary policy is the only driver of the Great Moderation.

The last two columns of Table 1 display results for a policy shift *within* the active regime.<sup>(15)</sup> A move to a relatively more anti-inflationary policy stance, within the active regime, is still capable of producing statistically significant breaks in the estimated innovation variances to inflation and output gap equations. The evidence of instability for both the innovation variance in the interest rate equation and the VAR coefficients is, once again, much weaker. The result that the VAR detects the shift in monetary policy as a break in the error variances does not hinge then on the move from passive to active policy.

Our reduced-form results show that, in contrast to the conventional presumption, the policy shift can exert its maximal impact on the VAR covariance matrix, as opposed to the VAR coefficients. It should be noted, however, that our results do *not* imply that we should now replace the previous, mistaken presumption with the opposite presumption that a change in the policy rule will always

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(14) Bootstrapping is performed as in Diebold and Chen (1996) applied to the VAR as a whole.

(15) Specifically, we increase  $\phi_\pi$  from 1.1 to 1.8 while keeping  $\rho_R$  and  $\phi_x$  constant to 0.9 and 0.5.

exert its maximal impact on the VAR covariance matrix. Rather, our findings imply that the evidence on instability of VAR innovation variances should be regarded as *uninformative* for discriminating between luck and policy.

Moving to counterfactual simulations, Stock and Watson (2002) and Ahmed, Levin, and Wilson (2004) show that switching the estimated VAR equation *coefficients* between the two sub-periods produces little change in the volatilities of the series. Switching the estimated *volatilities* of the reduced-form disturbances, in contrast, ‘inverts’ the outcomes with the macroeconomic stability now taking place over the first part of the sample. Table 2 reports the medians of the distributions of the standard deviations of the series, together with the 5th and 95th percentiles. Results are displayed for the baseline simulation under the active and passive regimes, and for counterfactual simulations in which we bootstrap the estimated reduced-form VARs after switching the estimated residuals across the two sub-periods.

*A switch in the estimated reduced-form shocks across sub-periods inverts the final outcome*, thus replicating the findings of Stock and Watson (2002) and Ahmed, Levin, and Wilson (2004) on actual data. In particular, super-imposing the reduced-form disturbances of the active period onto the estimates of the VAR coefficients for the passive sub-sample generates a substantial reduction in the volatilities of the three series. Analogously, coupling the VAR shocks of the passive period with the VAR coefficients estimated for the active regime moves macroeconomic volatility from the former to the latter period.

The findings of this section pose a serious challenge for the ability of existing reduced-form VAR evidence to assessing the role that monetary policy played in the Great Moderation. Conclusions that appear, at first sight, entirely sensible and appealing, turn out to be, upon closer inspection, potentially fragile. But, are structural methods any better?

## **5 Structural evidence**

On the basis of either time-varying or Markov-switching structural VARs for the United States, several authors have shown that switching monetary rules across sub-periods would have made little difference to the macroeconomic outcomes over the post-WWII era. This result has been interpreted as evidence against good policy, and in favour of good luck. In this section, we show that very similar results are obtained within a framework in which everything is driven by a move from passive to active policy.



## 5.1 Identification

The calibration of the parameters of the model implies impulse-response functions (henceforth, IRFs) for which the impact of the structural shocks on the three variables has the same sign under both active and passive regimes. In what follows, we identify therefore the three structural shocks in the VAR by imposing the following contemporaneous sign restrictions:

- a positive monetary policy shock has a positive impact on the interest rate, and a negative impact on inflation and the output gap;
- a positive demand non-policy shock has a positive impact on all variables;
- a positive cost push shock has a positive impact on inflation and the interest rate, and a negative impact on the output gap.

For each of the 10,000 simulations under either the active or passive regime we estimate a reduced-form VAR as in section 4, selecting the lag order on the basis of the Akaike information criterion. We compute the structural impact matrix,  $A_0$ , via the procedure recently introduced by Rubio-Ramirez, Waggoner, and Zha (2005).<sup>(16)</sup> Specifically, let  $\Omega = P \cdot D \cdot P'$  be the eigenvalue-eigenvector decomposition of the estimated VAR covariance matrix  $\Omega$ , and let  $\tilde{A}_0 \equiv P \cdot D^{\frac{1}{2}}$ . We draw an  $N \times N$  matrix,  $K$ , from the  $N(0, 1)$  distribution, we take the  $QR$  decomposition of  $K$ —that is, we compute matrices  $Q$  and  $R$  such that  $K=Q \cdot R$ —and we compute the structural impact matrix as  $A_0=\tilde{A}_0 \cdot Q'$ . Following Rubio-Ramirez, Waggoner, and Zha (2005), for each of the 10,000 simulations, we keep on drawing (i.e. computing rotations) until the sign restrictions are satisfied.

Given our calibration, we regard our choice of imposing the sign restrictions implied by the model as the most natural one. Other identifying restrictions, as for instance Cholesky, suffer from the notable drawback of being false under both policy regimes, and therefore they would make it difficult to interpret the results.

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(16) See <http://home.earthlink.net/~tzha02/ProgramCode/SRestrictRWZalg.m>.

## 5.2 Counterfactual simulations

VARs have been applied to U.S. inflation, unemployment, and a short rate. Primiceri (2005), for example, ‘brings Greenspan back in time’ by drawing the parameters of the monetary rule from their 1991-1992 posterior distribution, and imposing them over the entire sample period. His result of virtually no difference between the median of the distributions of counterfactual and actual series of unemployment and inflation is interpreted as *prima facie* evidence in favour of good luck, and against good policy.

Canova and Gambetti (2005) perform an alternative counterfactual exercise for the U.S. economy and they increase the estimated posterior mean of the coefficient on inflation in their time-varying VAR monetary rule by two standard deviations. As they stress, ‘[a] permanent more aggressive stance would have had important inflation effects in 1979, primarily in the medium run. However, at all dates in the 1980s and 1990s, the effect would have been statistically negligible.’ These results favour, apparently, the good luck hypothesis.

We simulate the model 10,000 times under both active and passive regimes, and for each simulation we proceed as follows: (i) based on the two simulated samples, we estimate two structural VARs as described in Section 5.1; (ii) we switch the estimated structural monetary rules in the two VARs across sub-periods, keeping everything else constant; (iii) we feed the estimated structural shocks to the VARs and we generate counterfactual series for the interest rate, inflation and the output gap;<sup>(17)</sup> (iv) we regress each of the ‘true’ simulated series on the corresponding counterfactual series *via* OLS, and we store the  $R^2$ .

To assess the ability of VAR counterfactual simulations to detect a break in the policy rule of the DSGE model, we also construct a benchmark  $R^2$ . For each simulation, we add two further steps: (v) we feed the ‘true’ structural shocks of one policy regime to the DSGE model calibrated for the other regime, and we generate counterfactual series for the interest rate, inflation and the output gap; (vi) we regress the ‘true’ series simulated using the structural macro model on the counterfactual series *via* OLS, and we store the  $R^2$ . It should be noted that the steps (v)-(vi) in the DSGE model are, conceptually, the counterparts of the steps (iii)-(iv) in the VAR, and therefore they will be used to construct the benchmark  $R^2$ .

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(17) For each counterfactual simulation we take as the initial conditions the first  $p$  values of  $Y_t \equiv [R_t, \pi_t, x_t]'$ , where  $p$  is the lag order selected by the AIC.

As the OLS regressions do not contain a constant, a  $R^2$  of one implies that ‘true’ and counterfactual series are identical, so that switching the monetary rules in either the estimated structural VARs or the DSGE model causes no change in the series. The lower the  $R^2$ , on the other hand, the greater are the changes implied by the switch in policy. More importantly, if VAR counterfactual simulations were a reasonable approximation to the switch in the DSGE model, then the distributions of the two  $R^2$  for VAR and DSGE model should be reasonably similar.

For each regime and variable, Figure 2 reports two objects: (in black) the distributions of the  $R^2$  for the regression of the ‘true’ inflation, output and interest rate on the counterfactual series in the VAR, and (in red) the distributions associated with the ‘true’ and counterfactual series in the DSGE model.

A number of interesting results emerges from Figure 2. First, the distributions implied by the VARs are always skewed relative to the distributions implied by the DSGE model, both for the passive (top row) and the active regime (bottom row). Second, for inflation and the interest rate, the modes of the  $R^2$  distributions of the DSGE model are far below the modes associated with the VAR, implying that the differences in the DGP are far larger than the differences detected by the counterfactual VARs. As for the output gap in the passive regime, the largest difference between ‘true’ and counterfactual series is now associated with the VAR. The distance between the modes, however, is still large, and it implies that the counterfactual simulations do not uncover the ‘true’ change in the DGP. Third, and more generally, imposing the structural monetary rule estimated for one regime onto the VAR estimated for the other regime produces limited changes in the counterfactual series. For inflation and the interest rate, the mode of the  $R^2$  distributions is one under both regimes, and the mass beyond 0.8 is above 50%.

Figure 3 complements the evidence in Figure 2 reporting the distributions of the standard deviation of the interest rate, inflation, and the output gap in the baseline VARs (black lines, labelled as ‘true’), and the distributions of the standard deviation for the three series based on the counterfactual simulations (red lines, labelled as ‘counterfactual’). While switching the estimated monetary rules between sub-periods produces some changes in the modes and distributions of the volatilities of the series, the evidence in Figure 2 suggests that the counterfactual VARs capture only a limited portion of the change implied by the policy switch in the DSGE model.

It is worth emphasising that earlier contributions obtain similar results performing, on actual data, the kind of counterfactual experiments we have reported in Figure 2. The results of the

counterfactual experiments have been interpreted, so far, as supportive of the good luck hypothesis. As the data generating process, here, only features improved monetary policy, our counterfactual simulations cast some doubts on the conventional interpretation of existing VAR evidence.

### 5.3 *Impulse-response analysis*

Little change over time in estimated impulse-response functions to an identified monetary policy shock has been traditionally regarded as evidence in favour of good luck and against good policy. Figure 4 shows the distributions of the estimated IRFs to a unitary monetary shock for the interest rate, inflation, and the output gap, based on 10,000 simulations of the model under both regimes.

We find little change in the distribution of the interest rate IRFs, some change for inflation, and a marked change for the output gap. Overall, the evidence in Figure 4 does not point decisively towards either luck or policy as the underlying cause of the Great Moderation. Together with the results in the previous sections, however, this evidence would hardly induce a researcher to identify the correct conclusion that policy is behind the changes in the DGP.<sup>(18)</sup>

## 6 Why do VARs miss the truth?

The results discussed in the previous sections provide an assessment of the ability of one of the best available econometric methods to identify correctly the underlying causes of the Great Moderation. Based on the New Keynesian workhorse model and a standard calibration as in Clarida, Gali, and Gertler (2000), reduced-form evidence on the simulated data appear uninformative and structural VARs seem to offer a distorted picture.

In this section, we explore *why* VARs are not capturing the truth. In order to identify the source of the problem, we inspect the VAR representations implied by the New Keynesian model under the two regimes.

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(18) A previous version of the paper based on the model estimated by Lubik and Schorfheide (2004) still produced the two key results of (i) statistically significant breaks in the VAR estimated innovation variances, and (ii) counterfactual simulations pointing against policy as the underlying cause of the changes in the DGP. Further, that calibration also produced little changes in the distributions of estimated IRFs to a unitary monetary shocks.

## 6.1 Mapping the structural model into a VAR

We solve the model as in Lubik and Schorfheide (2004). To this end, we define the state vector as  $\xi_t \equiv [R_t, \pi_t, x_t, \pi_{t+1|t}, x_{t+1|t}, g_t, z_t]'$ , the vector of structural shocks as  $\epsilon_t \equiv [\epsilon_{R,t}, \epsilon_{g,t}, \epsilon_{z,t}]'$ , and the vector of forecast errors as  $\eta_t \equiv [\eta_t^\pi, \eta_t^x]'$ , where  $\eta_t^\pi \equiv \pi_t - \pi_{t|t-1}$  and  $\eta_t^x \equiv x_t - x_{t|t-1}$ .

Augmenting (1)-(4) with the identities

$$\pi_t = \pi_{t|t-1} + \eta_t^\pi \quad (5)$$

$$x_t = x_{t|t-1} + \eta_t^x \quad (6)$$

the model can then be put into the canonical form due to Sims (2002):

$$\Gamma_0 \xi_t = \Gamma_1 \xi_{t-1} + \Psi \epsilon_t + \Pi \eta_t \quad (7)$$

where  $\Gamma_0$ ,  $\Gamma_1$ ,  $\Psi$  and  $\Pi$  are matrices conformable to  $\xi_t$ ,  $\epsilon_t$  and  $\eta_t$ . As shown by Lubik and Schorfheide (2003), under both determinacy and indeterminacy the vector of forecast errors can be expressed as a function of the vector of the structural shocks, which implies, under both regimes, a VAR(1) representation for  $\xi_t$ ,

$$\xi_t = A \xi_{t-1} + B \epsilon_t \quad (8)$$

The state-space representation of the model in terms of the three observable variables,  $R_t$ ,  $\pi_t$ ,  $x_t$ , implies the following observation equation

$$Y_t = C \xi_t \quad (9)$$

with  $Y_t \equiv [R_t, \pi_t, x_t]'$  and  $C = [I_3 \ 0_{3 \times 4}]$ . Notice that, in terms of the canonical 'A-B-C-D' representation of a state-space form, the matrix  $D = 0_{3 \times 3}$ .

We compute an equivalent minimal state realisation (henceforth, EMSR) of (8)-(9) via the MATLAB routine `ss.m`, and then we use a MATLAB code kindly supplied by Federico Ravenna for computing the finite-order VAR representation of a state-space form. Under the *passive regime*, we obtain the representation:

$$Y_t = \begin{bmatrix} 0.750 & 0.144 & 0.021 \\ 0.212 & 0.606 & -0.025 \\ 0.422 & -0.516 & 0.847 \end{bmatrix} Y_{t-1} + u_t, \text{Var}(u_t) = \begin{bmatrix} 2.331 & 5.676 & 4.143 \\ 5.676 & 22.539 & 19.493 \\ 4.143 & 19.493 & 26.723 \end{bmatrix} \quad (10)$$

whereas under the *active regime*, we obtain the reduced-form:

$$Y_t = \begin{bmatrix} 0.845 & 0.202 & 0.087 \\ 0.065 & 0.660 & -0.104 \\ 0.132 & -0.489 & 0.688 \end{bmatrix} Y_{t-1} + u_t, \text{Var}(u_t) = \begin{bmatrix} 1.735 & 2.933 & -0.449 \\ 2.933 & 7.876 & -0.162 \\ -0.449 & -0.162 & 4.243 \end{bmatrix} \quad (11)$$

A comparison between (10) and (11) provides additional insights into our results. It is intuitive to think that changes in the monetary policy rule of a DSGE model should exert their maximal impact on the coefficients of the VAR representation, with only a minimal impact on the VAR covariance matrix. Inspection of (10) and (11), however, reveals that such intuition is incorrect.

The change in the systematic component of monetary policy from the passive to the active regime has two consequences. First, and as expected, it causes changes in the AR matrix of the VAR. Second, and more strikingly, the policy move induces a dramatic decline in the innovation variances for two out of three series. In particular, the innovation variance of reduced-form shocks to the inflation equation decreases by 65.1%, while the fall for the corresponding variance of the output gap equation is equal to 84.1%. The VAR total prediction variance decreases by 42.1%, a ‘Great Moderation’ indeed.

These figures cast serious doubts on the presumption that changes in the systematic component of monetary policy should manifest themselves *mostly* as changes in the VAR coefficients. On the basis of this presumption, results from earlier contributions have been interpreted according to the notion that strong evidence of breaks in the VAR innovation variances, coupled with weak or no evidence of breaks in the VAR coefficients, is evidence against policy and in favour of luck. As (10) and (11) show, however, changes in the policy rule affect the *entire* structure of the VAR representation of a structural macro model, exerting an impact on both coefficients and covariance matrix. And, the presumption that the dominant impact of a policy shift will be on the VAR coefficients appears unwarranted.

The numerical values in (10) and (11) also provide a rationale for the finding of the reduced-form counterfactual simulations reported in Section 4. As the policy shift exerts its main influence on the VAR covariance matrices, it does not come as surprise that switching the VAR residuals across regimes ‘inverts’ the final outcome, with the Great Moderation now taking place in the former period.

## 6.2 Counterfactual simulations: VAR vs. DSGE model

A switch between the monetary rules in the structural VARs appears to bear no clear-cut relationship with a switch between the Taylor rules associated with passive and active regimes in the DSGE model. With the benefit of hindsight, this is not surprising, as the coefficients of the structural monetary rule—and, more generally, of *any* equation in a VAR—are complicated,

non-linear functions of the structural parameters of the DSGE model. As a consequence, switching the monetary rules in the VAR is *not* equivalent to switching the values of  $\phi_\pi$ ,  $\phi_x$ , and  $\rho_R$  across the policy regimes in the DSGE model.

The presumption behind performing counterfactual simulations in structural VARs is, in contrast, that switching the estimated interest rate equations should provide a reasonable approximation to the (correct) switch between the parameters of the monetary policy rule in the underlying structural model. The findings of Section 5.2, however, shows that this presumption may be fallacious. The important implication of our simple example is that the results obtained by switching the monetary rules in estimated VARs may carry little or no information for the effects of switching the monetary rules in the underlying macroeconomic models.

## 7 Conclusions

Vector autoregressions are powerful tools for forecasting and describing reduced-form correlations. If the task at hand, however, is to explain and interpret specific historical episodes, these methods may prove less successful, and their merits should be assessed on a case-by-case basis.

Despite being used in many applications, little was known, so far, on the ability of structural VARs to identify the sources of the Great Moderation. Using a popular model for monetary policy analysis, we have shown that VARs may fail to capture the role that monetary policy played in fostering the greater macroeconomic stability of recent years, as they tend to confuse good policy for good luck.

The implication of our findings is that some caution should be used when *interpreting* existing VAR results. Significant declines in the estimated VAR innovation variances and reverse ranking in counterfactual simulations have been interpreted, so far, as evidence in favour of good luck. We show that these findings are also consistent with the good policy hypothesis.

Given the recent advances in building methods for likelihood-based estimation and models for monetary policy analysis, estimating DSGE models in which monetary policy is allowed, but not required, to be passive has the potential to discriminate between the good policy and good luck explanations of the Great Moderation.

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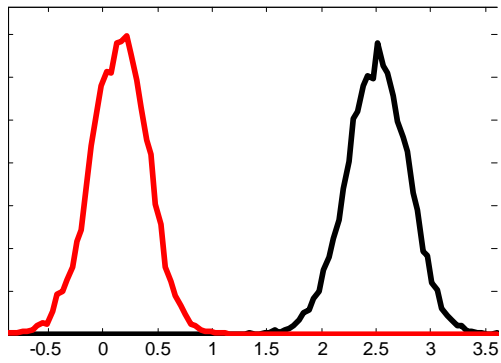
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<b>Table 1 - Testing for stability in the VAR equations: bootstrapped <i>p</i>-values for the Wald tests<sup>a</sup></b>				
<i>Equation:</i>	<i>Shift from passive to active policy:</i>		<i>Shift within the active regime:</i>	
	Innovation variance	Coefficients	Innovation variance	Coefficients
inflation	0.00 [.00; .01]	0.51 [.04; .95]	0.00 [.00; .01]	0.50 [.04; .95]
output gap	0.00 [.00; .00]	0.25 [.01; .82]	0.00 [.00; .02]	0.42 [.03; .95]
interest rate	0.34 [.14; .92]	0.06 [.00; .72]	0.16 [.00; .84]	0.24 [.00; .87]

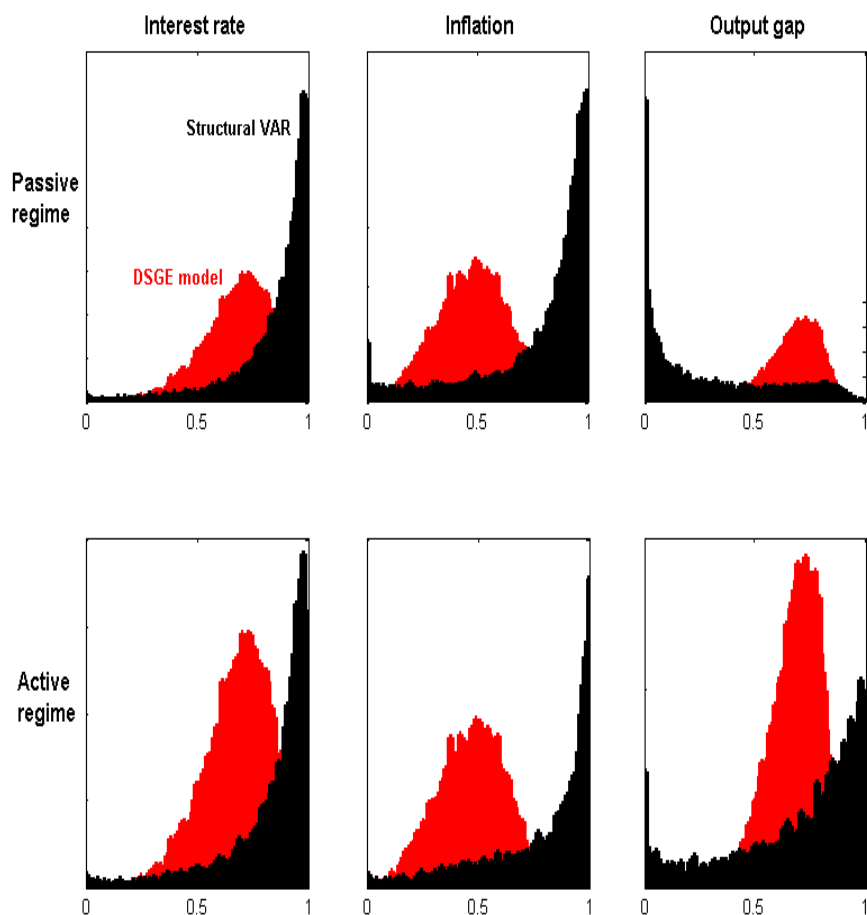
<sup>a</sup> Medians and 90% percentiles of the *p*-values distributions. 1,000 replications

<b>Table 2 - Standard deviations of the simulated series: counterfactual simulations (reduced-form)<sup>a</sup></b>			
	Interest rate	Inflation	Output gap
Passive regime:			
<i>baseline</i>	4.33 [3.05; 5.99]	6.48 [5.19; 8.18]	7.05 [5.61; 9.08]
<i>with active regime shocks</i>	2.99 [2.16; 4.54]	3.95 [3.09; 5.70]	4.85 [2.99; 7.63]
Active regime:			
<i>baseline</i>	3.80 [2.62; 5.47]	4.20 [3.24; 5.61]	4.80 [3.42; 6.78]
<i>with passive regime shocks</i>	5.69 [3.59; 9.18]	6.20 [4.96; 8.56]	6.70 [5.47; 9.34]

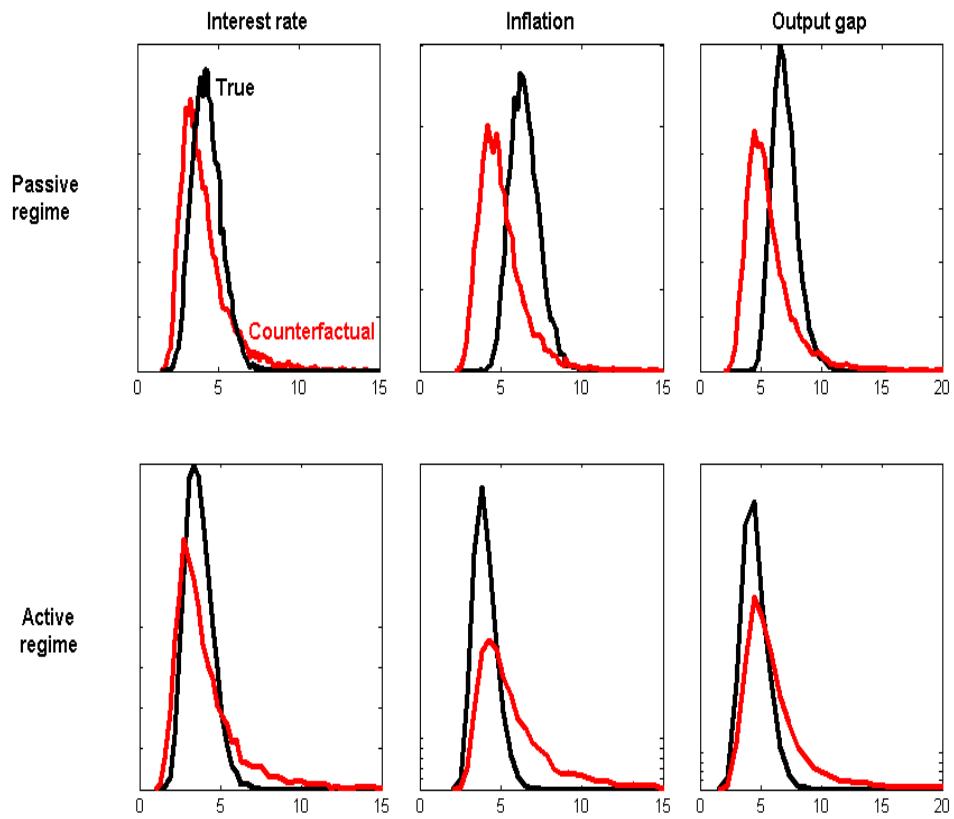
<sup>a</sup> Median and 90% percentiles of the distributions. 10,000 replications



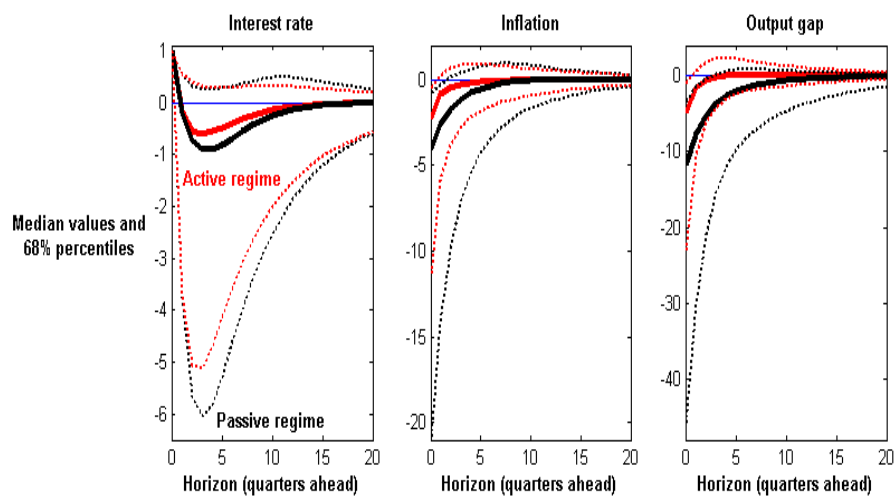
**Chart 1: Distributions of the VAR estimated total prediction variance, and of the estimated variances of VAR innovations: passive and active regimes**



**Chart 2: Distributions of the  $R^2$  in the regressions of ‘true’ interest rate, inflation and output gap series on the counterfactual series. Counterfactual simulations are based on the structural VARs and the DSGE model.**



**Chart 3: Distributions of the standard deviations of the interest rate, inflation, and the output gap: ‘true’ and counterfactual simulations**



**Chart 4: Estimated impulse-response functions to a unitary monetary shock based on sign restrictions**