UNIVERSITY OF SURREY

Discussion Papers in Economics

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DP 06/08

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ISSN: 1749-5075

Taylor-type rules versus optimal policy in a Markov-switching economy*

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April 28, 2008

Abstract

We analyse the effect of uncertainty concerning the state and the nature of asset price movements on the optimal monetary policy response. Uncertainty is modelled by adding Markov-switching shocks to a DSGE model with capital accumulation. In our analysis we consider both Taylor-type rules and optimal policy. Taylor rules have been shown to provide a good description of US monetary policy. Deviations from its implied interest rates have been associated with risks of financial disruptions. Whereas interest rates in Taylor-type rules respond to a small subset of information, optimal policy considers all state variables and shocks. Our results suggest that, when a bubble bursts, the Taylor rule fails to achieve a soft landing, contrary to the optimal policy.

JEL Classification: E52, E58.

Keywords: Asset Prices, Monetary Policy, Markov Switching.

*The authors are grateful to participants in seminars at the Portuguese Catholic University (Porto) and at the University of Minho, in particular to Francisco Veiga, Luis Aguiar-Conraria and Ricardo Sousa.

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1 Introduction

Several authors have identified a break in output growth volatility, in the US, around the mid-1980s — see, for example, (Kim and Nelson 1999) and (McConnell and Perez-Quiros 2000). According to (Stock and Watson 2002) the standard deviation of the growth rate of GDP was one-third less during 1984 to 2002 than it was during 1960 to 1983. The decline in the volatility of inflation and real GDP, in the last two decades, in the US and in other industrialised countries, has been dubbed the Great Moderation or the Long Boom. According to (Taylor 2007), this may have been the most important macroeconomic event in the last half century. Lower volatility of output in the post-1984 period is associated with less frequent and less severe recessions: since 1984, the National Bureau of Economic Research identified only two recessions — one in 1990 and the other in 2001 — which were among the mildest and shortest recessions since the Second World War, with duration from peak to trough of eight months each.

These changes in the business cycle have raised the question of what has been the role of the Federal Reserve in this new regime of the US economy. Although structural changes in the economy and good luck concerning the shocks that hit the economy during that period had certainly a role — see, for example, (Stock and Watson 2002) and (McConnell and Perez-Quiros 2000) —, it has been argued that improvements in monetary policy were crucial in generating a lower inflation and a more stable output — see, for example, (Bernanke 2004) and (Clarida, Galí, and Gertler 2000). Among the changes in monetary policymaking is the apparent adoption of the so-called Taylor principle, which implies a response of the interest rate policy instrument to changes in inflation with a coefficient greater than one. In fact, a more aggressive reaction of the interest rate to inflation and to the output gap is an important difference between the period of the Great Moderation and the previous period

— see, for example, (Clarida, Galí, and Gertler 2000).

An extensive literature on monetary-policy rules suggests that to follow a specific simple rule may be the best prescription to a good monetary policy — see, for example, (Taylor 1999). The Taylor rule was proposed as a guideline for assessing interest rate decisions (Taylor 1993). Additionally, financial market analysts, scholars and central banks' staff have been using monetary policy rules increasingly to forecast interest rates and to evaluate and describe central bank policy actions — see, for example, (Judd and Trehan 1995) and (Blinder and Reis 2006). The Taylor rule has provided a good description of monetary policy under Alan Greenspan's mandate — see (Rudebusch 2006) and Figure 1. However, Taylor rule's inflation and unemployment coefficients are better seen as "historically average responses"[1] rather than as a literal description of the actual monetary policy of the Federal Reserve (Blinder and Reis 2006). Actually, the Federal Reserve has deviated from interest rate movements implied by the Taylor rule on several occasions. Those deviations of the US monetary policy have been associated with high risks of financial markets disruptions (Greenspan 2004). The stock market collapse in 1987 and the 1998 Russian debt default, followed by the demise of the Long-Term Capital Management hedge fund were two such episodes of monetary policy easing relative to the Taylor rule prescription. The terrorist attack of September 11 was another instance involving a high risk of financial instability and an aggressive monetary easing. More recently, following the sub-prime crisis, the Federal Reserve has cut the Feds Fund rate in 300 basis points, between August 2007 and March 2008.

(Taylor 2007), although recognising that the Taylor rule is not supposed to be followed mechanically, argues that monetary policy might deliver better results, in terms of low inflation and output variability, by staying closer to the

[1] This was the expression used by (Greenspan 2004).

rule. (Taylor 2007) sees more disadvantages than advantages in deviations of interest rates from the movements implied by the Taylor rule. On the other hand, (Greenspan 2004) argues that in events of the type described above simple policy rules would be inadequate as they are unable to take into consideration every contingency. In the same vein, (Svensson 2003) argues that a commitment to a simple instrument rule may be far from optimal in some circumstances. In fact, (Greenspan 2004) advocates instead a risk-management approach, which "emphasises understanding as much as possible the many sources of risk and uncertainty that policymakers face" (Greenspan 2004, p. 37). (Svensson and Williams 2005) develop a procedure to solve optimal monetary policy problems under model uncertainty which, in their words, is consistent with Greenspan's risk-management approach. (Svensson and Williams 2005) approach to optimal policy under model uncertainty considers the whole probability distribution of future variables.

In this paper, we apply (Svensson and Williams 2005) solution methods to a DSGE model with investment and uncertainty concerning the nature of asset price movements. In (Dupor 2005) model, agents cannot distinguish between fundamental and non-fundamental shocks in asset prices. In this paper, we add an additional source of uncertainty to Dupor's setting. The additional uncertainty affects the behaviour of asset prices via a Markov-switching autoregressive coefficient in both fundamental and non-fundamental shocks. The assumption of Markov-switching non-fundamental shocks adds realism to the model, judging by the empirical evidence reported in, among others, (Cecchetti, Lam, and Mark 1990), (Bonomo and Garcia 1994) and (Driffill and Sola 1998).

We use this setting, where fads and bubbles in asset prices are modelled as non-linear processes, to compare the performance of Taylor-type rules with the optimal policy in stabilising the economy. In the Taylor-type rules that we consider in this paper, the interest rate reacts with fixed coefficients to a small subset of information available to the central bank, namely, inflation, the output gap and, possibly, asset prices. On the other hand, optimal rules take into account all state variables, shocks and the uncertainty in the economy, namely, in our economy it takes into account the switching nature of asset prices and therefore the probability of a crash. To obtain the results reported below, we employed the methods proposed by (Svensson and Williams 2005), assuming full information under commitment.[2]

We focus our analysis on output and real interest rate adjustment when the asset price bubble bursts, namely, we compare the performance of Taylor-type rules and optimal policy during and after a bubble episode. Simulations seem to suggest that the optimal policy is more effective in containing the bubble-induced expansion, producing a soft landing. Additionally, our results suggest that real interest rates are less volatile under Taylor-type rules.

Our exposition is organised as follows. Section 2 presents the model and discusses the monetary policy framework. Section 3 evaluates the performance of the economy under Taylor-type rules and optimal policy. Section 4 concludes.

2 A model with Markov-switching asset prices

In a world where asset price movements simply reflect fundamentals, their only role in monetary policy making is as a conveyer of information about the state of the economy. However, there is evidence that asset prices are partly driven by non-fundamental movements, that is, there are fads or bubbles — e.g., (Shiller 2000). In these periods, asset prices may induce inefficient decisions by firms and consumers, and therefore destabilise the economy. This has been the main argument for monetary policy to respond directly to asset prices — see, for

[2](Alexandre, Bação, and Driffill 2007) use those methods in the context of an open-economy model.

example, (Cecchetti, Genberg, Lipsky, and Wadhwani 2000) and (Dupor 2005). However, there is disagreement on whether policymakers should target asset prices because of the uncertainty concerning the nature of the forces driving asset prices. Some authors argue that uncertainty concerning the magnitude of misalignments in asset prices is not trivial and that it might imply that the welfare benefits from including them in the policy reaction function may vanish very easily — see, among others, (Gilchrist and Saito 2006), (Alexandre and Bação 2005) and (Tetlow 2004).

In this paper, we use (Dupor 2005)'s DSGE model with capital accumulation and adjustment costs to evaluate the performance monetary policy rules in stabilising the economy. This model, described in the next section, was developed to study the optimal response of monetary policy to asset prices when agents cannot discern the nature of the shocks that move asset prices. In Dupor's model, expectations of future returns to investment may be affected by unwarranted views about future productivity, resulting in "irrational exuberance" and overinvestment. In this paper, we add an additional source of uncertainty to Dupor's setting. The additional uncertainty affects the behaviour of asset prices via a Markov-switching autoregressive coefficient in both fundamental and non-fundamental shocks. We therefore assume a Markov-switching process, with booming periods of continuous growth in asset prices being interrupted by sudden corrections, aiming to capture the complex behaviour of financial markets.

This setting allows us to compare the performance of Taylor-type rules with the optimal policy, when firms and policymakers face uncertainty concerning the driving forces of asset prices and the moment when bubbles in asset prices will collapse.

In the next sections we provide a more detailed analysis of the model and of the monetary policy framework we use in our analysis.

2.1 Uncertainty in a model with investment

In this paper, we use (Dupor 2005)'s DSGE model with capital accumulation to evaluate the performance of monetary policy rules when a bubble bursts. In Dupor's model, expectations of future returns to investment may be affected by unwarranted views about future productivity, resulting in "irrational exuberance" and overinvestment. Below we briefly sketch the model, referring the reader to (Dupor 2005) for further details.

The model's "household-firms" are simultaneously consumers (utility maximizers subject to a budget constraint) and producers (under monopolistic competition). They sell labour, and hire the labour used in production, in a competitive labour market, while the capital stock is rented from "investment-firms".

Investment-firms are responsible for capital accumulation decisions. Dupor assumes there are costs of adjusting capital, represented by a function Φ. The investment-firms' period profit is given by receipts from renting capital ($r_t k_t$), minus investment expenditure ($k_{t+1} - (1-\delta)\, k_t$, where δ is the depreciation rate), minus capital adjustment costs:

$$z_t = r_t k_t + (1-\delta)\, k_t - k_{t+1} - \Phi\left(\frac{k_{t+1}}{k_t}\right) k_t \tag{1}$$

Investment-firms maximise discounted expected profits:

$$z_t + E_t \sum_{j=1}^{\infty} \left[\beta_{t+j} \tilde{z}_{t+j}\right] \tag{2}$$

where β_{t+j} is the discount factor and $\tilde{z}_{t+j}$ is the process investment-firms expect profits to follow in the future. The following assumption is used:

$$\tilde{z}_{t+j} = \theta_{t+j} r_{t+j} k_{t+j} + (1-\delta)\, k_{t+j} - k_{t+j+1} - \Phi\left(\frac{k_{t+j+1}}{k_{t+j}}\right) k_{t+j} \tag{3}$$

The factor θ_{t+j} is the crucial element: it represents non-fundamental shocks (when $\theta_{t+j} \neq 1$) that distort investment decisions. Dupor uses a (log-)linear specification for the non-fundamental shock, chosen to produce a hump-shaped effect:

$$\hat{\theta}_t = \omega\hat{\theta}_{1,t} + (\omega - 1)\hat{\theta}_{2,t} \tag{4}$$

$$\hat{\theta}_{j,t} = \rho_j\hat{\theta}_{j,t-1} + \hat{\varepsilon}_t^{\theta} \quad (j = 1, 2) \tag{5}$$

where $\hat{\varepsilon}_t^{\theta}$ is white noise.

Instead we use a Markov-switching specification, to replicate the impact of a sudden burst in asset prices, characteristic of financial crises. We assume there are two states. The two states aim at capturing the complex behaviour of financial markets, which have quiescent periods, when they seem to be driven by fundamentals, interspersed with periods of "irrational exuberance". Therefore, we assume that in the first state the shocks have no persistence:

$$\hat{\theta}_{j,t} = \hat{\varepsilon}_t^{\theta} \quad (j = 1, 2) \tag{6}$$

In the second, exuberant regime, shocks are mildly explosive. This is achieved by multiplying Dupor's autoregressive coefficients by 1.6, which yields autoregressive coefficients close to 1.09:

$$\hat{\theta}_{j,t} = 1.6\rho_j\hat{\theta}_{j,t-1} + \hat{\varepsilon}_t^{\theta} \quad (j = 1, 2) \tag{7}$$

When the economy moves from state 1 to state 2, investment-firms expect profits to increase exponentially and a bubble develops. The bubble bursts when the economy moves from state 2 back to state 1. The state of the economy is assumed to evolve as a Markov chain with the following probability transition matrix:

$$P = \begin{bmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{bmatrix} \tag{8}$$

where $p_{ij} = 1 - p_{ii}$ (when $i \neq j$) and p_{ij} is the probability of moving from state i in the current period to state j in the next period. In this model, the policymaker is uncertain about the state of the economy in the next period. However, the transition probabilities are known and exogenous. In our computations we used the values 0.25, 0.50 and 0.75 for p_{ii}, though here we only report results obtained with $p_{11} = p_{22} = 0.5$, which were found to be representative. The other parameters in the model take the same values as in (Dupor 2005, Table 1, page 738).

We focus our analysis on the comparison of the behaviour of the optimal policy and of the Taylor rule. In the case of the Taylor rule, the interest rate reacts to output and inflation with coefficients of 0.5 and 1.5, respectively (Taylor 1993).

The solution of the model is obtained using the method proposed by (Svensson and Williams 2005) for solving Markov-switching rational expectations models. Appropriately for our purposes, these authors argue that their approach to model uncertainty is consistent with Greenspan's risk-management approach, mentioned in the Introduction.

2.2 Taylor-type rules

Simple, or Taylor-type, rules have been widely discussed among academics in monetary policy analysis. Several arguments have been used in its defense. On one hand, it has been argued that simple rules perform nearly as well as optimal rules (see, for example, (Rudebusch and Svensson 1999)). On the other hand, it has been argued that simple rules are very robust to several types of uncertainty (see, for example, (Levin, Wieland, and Williams 1999)). We therefore consider a set of simple rules to see how they compare to the optimal policy rule and how good they are in dealing with uncertainty concerning movements in asset prices. The set of rules used in our computations are summarised in Table 2.

We consider the original Taylor rule (Taylor 1993), where the interest rate reacts to output and inflation with coefficients of 0.5 and 1.5, respectively. As mentioned in the Introduction, this rule has been shown to provide a good description of the US monetary policy since 1987. Following the now extensive literature on asset prices and monetary policy (see, for example, (Cecchetti, Genberg, Lipsky, and Wadhwani 2000)), we also look at the results for a Taylor rule that includes a reaction to asset prices (TR+q). The coefficient on asset prices is 0.1, as in (Bernanke and Gertler 1999).

Several authors have concluded that monetary policy responds to the expected value of inflation rather than to current or past inflation (see, for example, (Clarida, Galí, and Gertler 2000)). (Levin, Wieland, and Williams 2003) provide a discussion of the rationale and robustness of inflation-forecast based rules. We consider a simple inflation-forecast based policy rule (IFB) where the interest rate responds to deviations of expected inflation from the target. We also experiment an inflation-forecast based rule with an expected output term (IFB+y) and with an expected output term and an asset price term (IFB+y+q). The coefficients in the inflation-forecast based policy rules are as in the Taylor rule, that is, 1.5 coefficient in the expected inflation and 0.5 in the expected output. The coefficient on asset prices is 0.1, again as in (Bernanke and Gertler 1999). We also tried a stronger reaction to expected inflation, with coefficient 2.0 in the case of rule IFB+y+q aggressive. The coefficients on $E_t\pi_{t+1}$ and $E_t y_{t+1}$ for forecast-based rules were chosen so as to be close to 1.5, among values for which the algorithm of (Svensson and Williams 2005) could find a solution to the model.

3 Soft landing in a Markov-switching economy

In this paper we investigate the limits of simple Taylor-type rules at moderating the disruptive effects of asset market disturbances and whether central banks may have incentives to deviate from the prescriptions of Taylor-type rules. We do that using the optimal policy, described above, as a benchmark. We only present the results for $p_{11} = 0.5$ and $p_{22} = 0.5$, as we did not find significant differences in our computations for the other combinations of transition probabilities.

We start by computing the unconditional standard deviations of the variables of the model, for the optimal policy and for Taylor-type rules. The results are presented in Table 3. Except for the simple inflation-forecast based rule (IFB), output and its components (consumption and investment) are much more stable under Taylor-type rules than under the optimal policy. From the results in Table 3, we would conclude that the Taylor rule is significantly more effective at stabilising output, but not employment. In fact, output is much more stable (around ten times) under a Taylor rule than under the optimal policy. The performance of the simple inflation-forecast based rule, which, in general, delivers the worst results in terms of volatility, improves significantly when the interest rate reacts to expected output and to asset prices. These results may be related with the findings of (Levin, Wieland, and Williams 2003) that including an output gap term makes inflation-forecast based rules more robust. The real interest rate is always much more stable when policymakers follow Taylor-type rules than when they follow the optimal policy, which may be a sign that the Taylor rules are not aggressive enough.

To analyse the adjustment process of output following the collapse of asset prices, under Taylor-type rules and optimal policy, we investigate the dynamics of the economy when a persistent non-fundamental shock hits the economy. We do this evaluation by means of impulse-response functions, Figure 2 to 8, and by analysing t-steps ahead standard deviations of output following a persistent non-fundamental shock in asset prices, reported in Tables 4 and 5.

Concerning the impulse-response functions, except for the simple inflation-based forecast rule, which seems to produce very unstable patterns, the results are very similar for the whole set of simple Taylor-type rules considered in this analysis. Therefore, we focus our comparison on Figures 2 and 3.

A non-fundamental shock causes an increase in asset prices, which induces a jump in gross investment and output. As long as the bubble inflates, asset prices, investment and output continue to grow. This overinvestment implies a reduction of the resources available for consumption as found in (Blanchard 2000). When the bubble bursts, investment and asset prices collapse and so does output. However, there are important differences in the magnitude and volatility patterns for the optimal policy (Figure 2 and for the Taylor rule (Figure 3).

The optimal policy motivates a more aggressive monetary policy reaction than the Taylor rule when the economy is hit by a persistent non-fundamental shock — see the lower-left panel. The stronger reaction of the optimal policy guarantees that asset prices stay closer to its equilibrium value under the optimal policy than under the Taylor rule. That behaviour of asset prices implies that investment and output, under the optimal policy, do not deviate as much from their equilibrium values as they do for the Taylor rule. Actually, from the observation of the output impulse-response function (see the lower-right panel of Figure 2) the optimal policy seems to be more effective in smoothing the output path to the steady-state, resulting in a soft landing of the economy after a crash in asset prices. The optimal policy achieves a soft landing by stimulating consumption.

Turning now to the t-steps ahead standard deviations of output and real interest rate, the results reflect the uncertainty of the agents concerning the future evolution of output and the real interest rate, given that a persistent non-fundamental shock has hit the economy. Table 4 portrays the difference between the hard landing brought about by a Taylor rule and the soft landing under the optimal policy. While the hard landing makes output volatile in the near future, the soft landing increases dispersion in the not so near future.

Longer-term output forecasts will be more accurate under a Taylor rule than under the optimal policy. The lack of aggressiveness of the Taylor rule in the event of an asset price boom-bust episode is also evident on Table 5: the conditional volatility of the real interest rate is always lower under the Taylor rule, i.e., the real interest rate will be harder to forecast under the optimal policy.

4 Conclusion

In this paper we tried to give an answer to the following question: Given the possibility of an asset price bubble burst and a subsequent hard landing, what is the optimal monetary policy reaction? When asset prices are driven by non-fundamental shocks, both the optimal policy and the Taylor rule seem to suggest that central banks should keep increasing the real interest rate, and to decrease it sharply when the bubble bursts. However, the Taylor rule suggests a lower increase in the real interest rate. The sharper movements in the real interest rate induced by the optimal policy suggest that the standard Taylor rule may be not aggressive enough in the event of an asset price boom-bust episode.

Our results suggest that overall Taylor-type rules may be very effective at stabilizing output and the real interest rate. However, they also indicate that if central banks do care about output future's path and aim at a softlanding — which according to (Meyer 2004), (Greenspan 2007) and (Woodford 2007) seems to be the case — following a bubble burst they increase liquidity more than the Taylor rule prescribes. These conclusions seem to be in accordance with previous findings in the literature on monetary policy and asset prices (Mishkin 2007) and suggest that further research on the relation between deviations from the Taylor rule and volatility in financial markets may be justified.

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Tables

Table 1: Parameters

α	β	δ	A	σ_{ϵ^a}	σ_{ϵ^θ}	$\sigma_{\underline{a}}$	ρ_1	ρ_2	ω
0.36	0.95	0.09	1	1.2	0.6	1.5	0.687	0.679	0.5

Table 2: Policy rules and coefficients in the log-linearized model

Rule	p_{11}	p_{22}	π_t	y_t	q_t	$E_t\pi_{t+1}$	$E_t y_{t+1}$
optimal policy	all	all	—	—	—	—	—
TR	all	all	1.5	0.5	—	—	—
TR+q	all	all	1.5	0.5	0.1	—	—
IFB	0.25	0.25	—	—	—	1.5	—
IFB	0.25	0.50	—	—	—	1.5	—
IFB	0.25	0.75	—	—	—	1.7	—
IFB	0.50	0.25	—	—	—	1.9	—
IFB	0.50	0.50	—	—	—	1.6	—
IFB	0.50	0.75	—	—	—	1.8	—
IFB	0.75	all	—	—	—	2.8	—
IFB+y	all	all	—	—	—	1.5	0.5
IFB+y+q	all	all	—	—	0.1	1.5	0.5
IFB+y+q agg.	all	all	—	—	0.1	2.0	0.5

optimal policy: the optimal policy reacts to all state variables and shocks

TR: Taylor rule

IFB: Inflation forecast based rule

all: 0.25, 0.5, 0.75

Table 3: Unconditional standard deviations with $p_{11} = p_{22} = 0.5$

	optimal	TR	TR+q	IFB	IFB+y	IFB+y+q	IFB+y+q agg.
c	0.8483	0.0785	0.0773	0.7578	0.0034	0.0033	0.0054
n	1.1605	2.0004	2.0097	2.3162	2.344	2.344	2.3439
k	1.2113	0.1107	0.1093	1.4319	0.0122	0.0118	0.0152
y	2.4082	0.2449	0.238	1.6335	0.0109	0.01	0.0142
$r.i.r.$	0.8058	0.0866	0.0836	0.2508	0.0018	0.0018	0.0018

Table 4: t-steps ahead standard deviation of output after a persistent non-fundamental shock, $\sqrt{V(y_t|s_0 = 2)}$, relative to the optimal policy, with $p_{11} = p_{22} = 0.5$

t	optimal	TR	TR+q	IFB	IFB+y	IFB+y+q	IFB+y+q agg.
1	1	12.7371	11.8506	24.1346	13.894	12.4058	12.8685
2	1	8.4769	7.9536	13.9838	10.1253	9.1209	9.4247
3	1	6.2174	5.8693	9.5364	7.7958	7.0673	7.304
4	1	4.8223	4.5727	7.3275	6.2326	5.6774	5.8748
5	1	3.8854	3.6957	6.0335	5.1253	4.685	4.8542
6	1	3.2189	3.0673	5.107	4.3071	3.9461	4.0925
7	1	2.723	2.5968	4.3845	3.6805	3.3764	3.5032
8	1	2.3404	2.2316	3.9043	3.186	2.9238	3.0336
9	1	2.036	1.9397	3.7901	2.7852	2.5551	2.6498
10	1	1.7874	1.7005	4.1034	2.4531	2.2484	2.3296
11	1	1.5801	1.5004	4.7562	2.1729	1.9888	2.0579
12	1	1.404	1.3304	5.5896	1.9328	1.7658	1.8243
13	1	1.2524	1.1839	6.4637	1.7244	1.5722	1.6212
14	1	1.1203	1.0563	7.2744	1.542	1.4026	1.4431
15	1	1.0041	0.9443	7.9442	1.3808	1.2529	1.286
16	1	0.9012	0.8453	8.4152	1.2378	1.1201	1.1468
17	1	0.8096	0.7573	8.6487	1.1101	1.0019	1.0228
18	1	0.7276	0.6788	8.6288	0.9959	0.8963	0.9123
19	1	0.6541	0.6086	8.3729	0.8934	0.8017	0.8135
20	1	0.588	0.5457	7.9487	0.8014	0.7171	0.7252

Table 5: t-steps ahead standard deviation of the real interest rate after a persistent non-fundamental shock, $\sqrt{V(y_t|s_0 = 2)}$, relative to the optimal policy, with $p_{11} = p_{22} = 0.5$

t	optimal	TR	TR+q	IFB	IFB+y	IFB+y+q	IFB+y+q agg.
1	1	0.7954	0.818	0.0869	0.8566	0.8811	0.886
2	1	0.7425	0.7667	0.0958	0.7459	0.7809	0.7866
3	1	0.7109	0.736	0.1335	0.6826	0.7233	0.7293
4	1	0.6901	0.7156	0.1956	0.6416	0.6856	0.6916
5	1	0.6765	0.7022	0.278	0.6147	0.6604	0.6666
6	1	0.6684	0.6941	0.3758	0.5982	0.6446	0.6512
7	1	0.6647	0.6901	0.4836	0.59	0.6361	0.6433
8	1	0.6642	0.6895	0.5942	0.5884	0.6336	0.6418
9	1	0.6663	0.6913	0.6997	0.5918	0.6358	0.6453
10	1	0.6701	0.6949	0.7913	0.599	0.6417	0.6528
11	1	0.675	0.6997	0.8618	0.609	0.6504	0.6635
12	1	0.6805	0.7052	0.9094	0.6208	0.661	0.6765
13	1	0.686	0.7108	0.9462	0.6336	0.6727	0.691
14	1	0.6909	0.716	1.0118	0.6466	0.685	0.7062
15	1	0.6949	0.7203	1.1784	0.659	0.6969	0.7215
16	1	0.6972	0.7232	1.5186	0.6702	0.7078	0.736
17	1	0.6975	0.724	2.0631	0.6794	0.717	0.7489
18	1	0.695	0.7221	2.8038	0.6859	0.7237	0.7593
19	1	0.6892	0.7171	3.7142	0.6889	0.7271	0.7665
20	1	0.6797	0.7082	4.754	0.6877	0.7265	0.7697

Figure 1: Federal funds rate target and the target computed using Taylor's rule

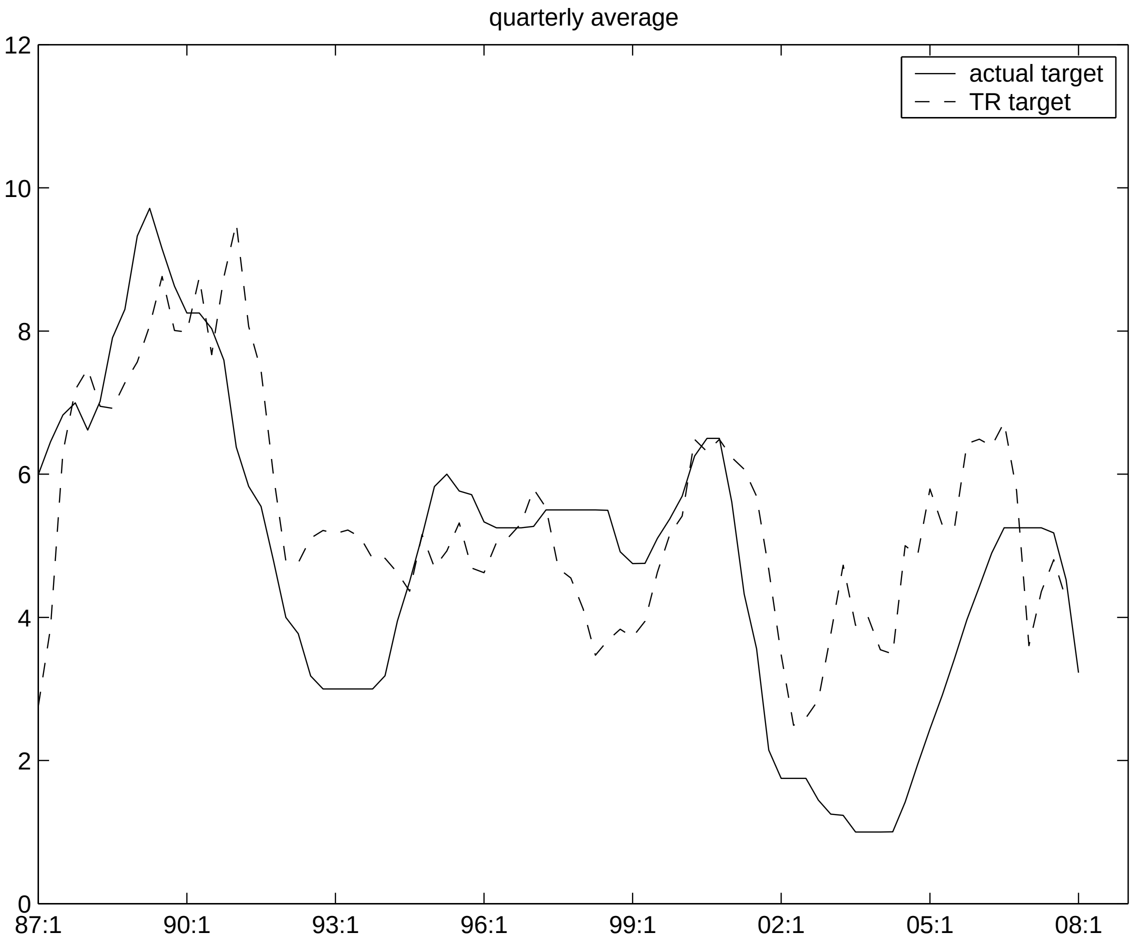

Figure 2: Impulse-response functions when there is a persistent non-fundamental shock in period 1 and the policymaker employs the optimal policy

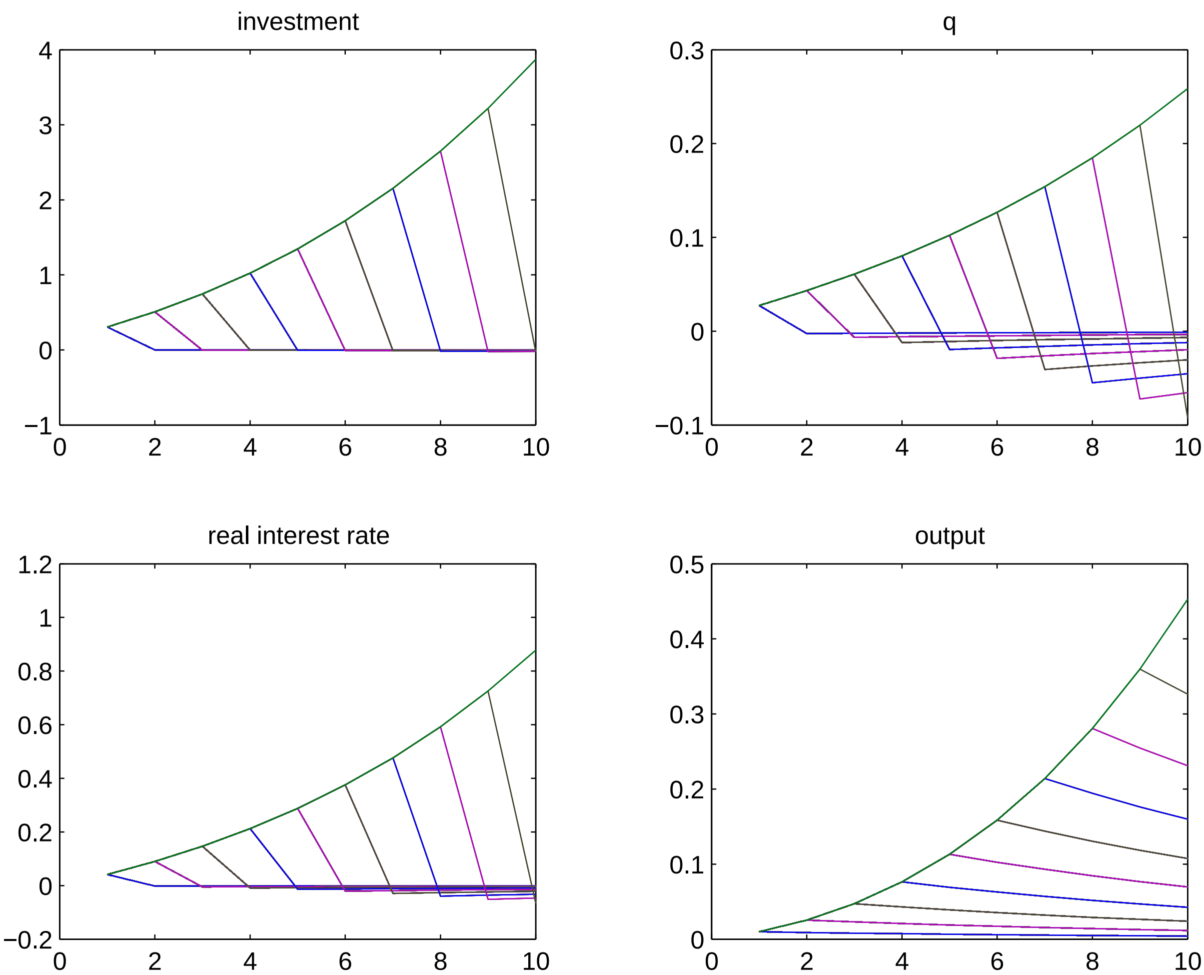

Figure 3: Impulse-response functions when there is a persistent non-fundamental shock in period 1 and the policymaker employs the TR

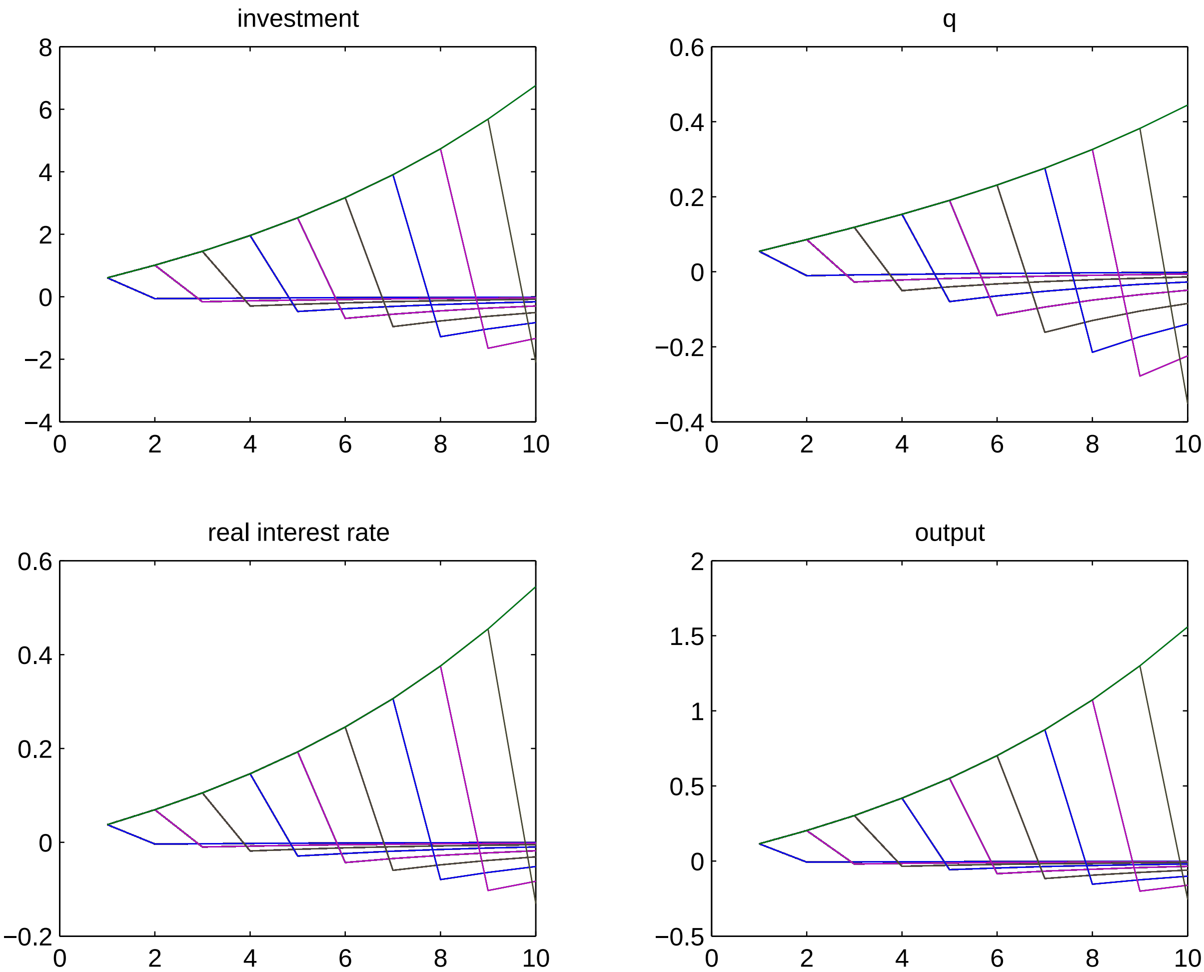

Figure 4: Impulse-response functions when there is a persistent non-fundamental shock in period 1 and the policymaker employs the TR+q

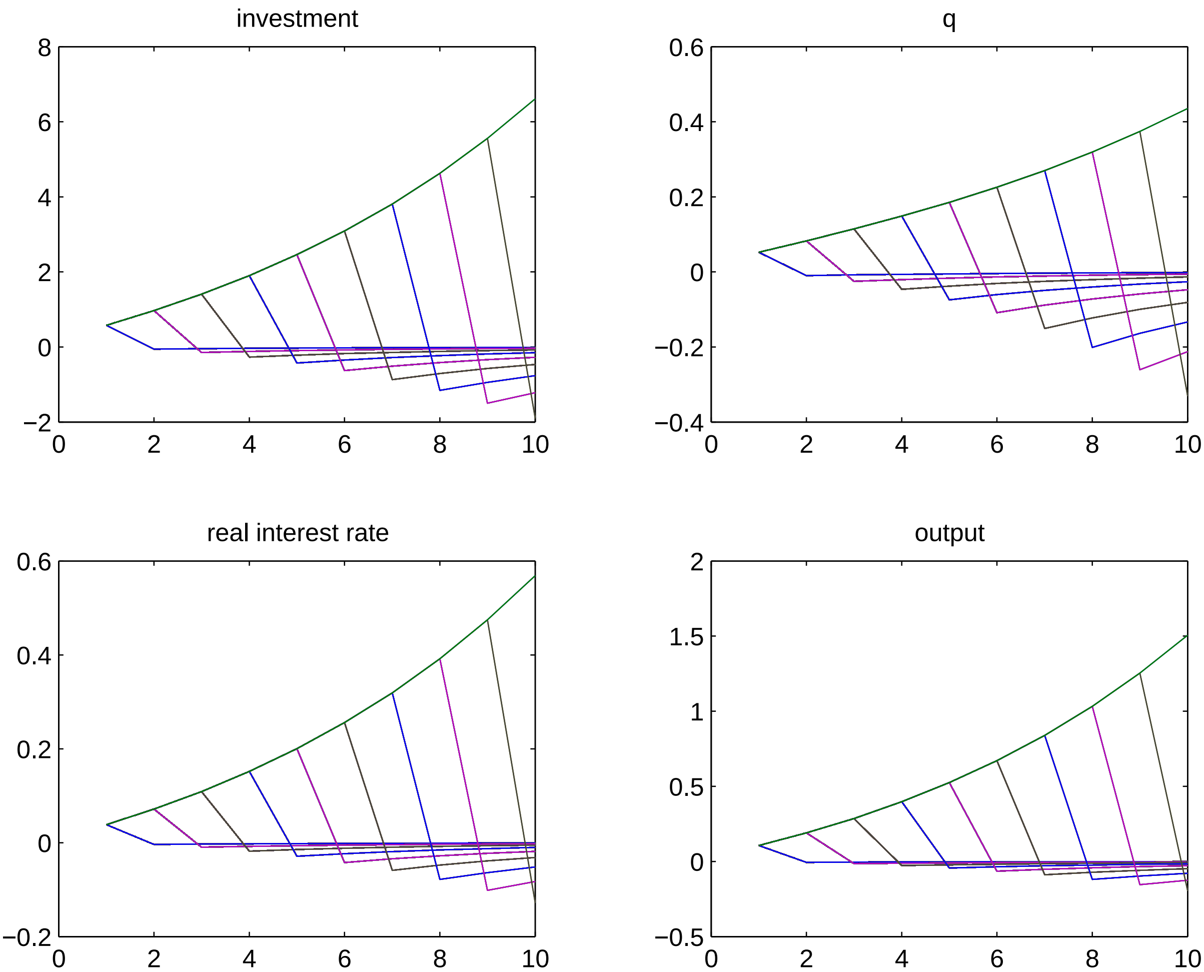

Figure 5: Impulse-response functions when there is a persistent non-fundamental shock in period 1 and the policymaker employs the IFB

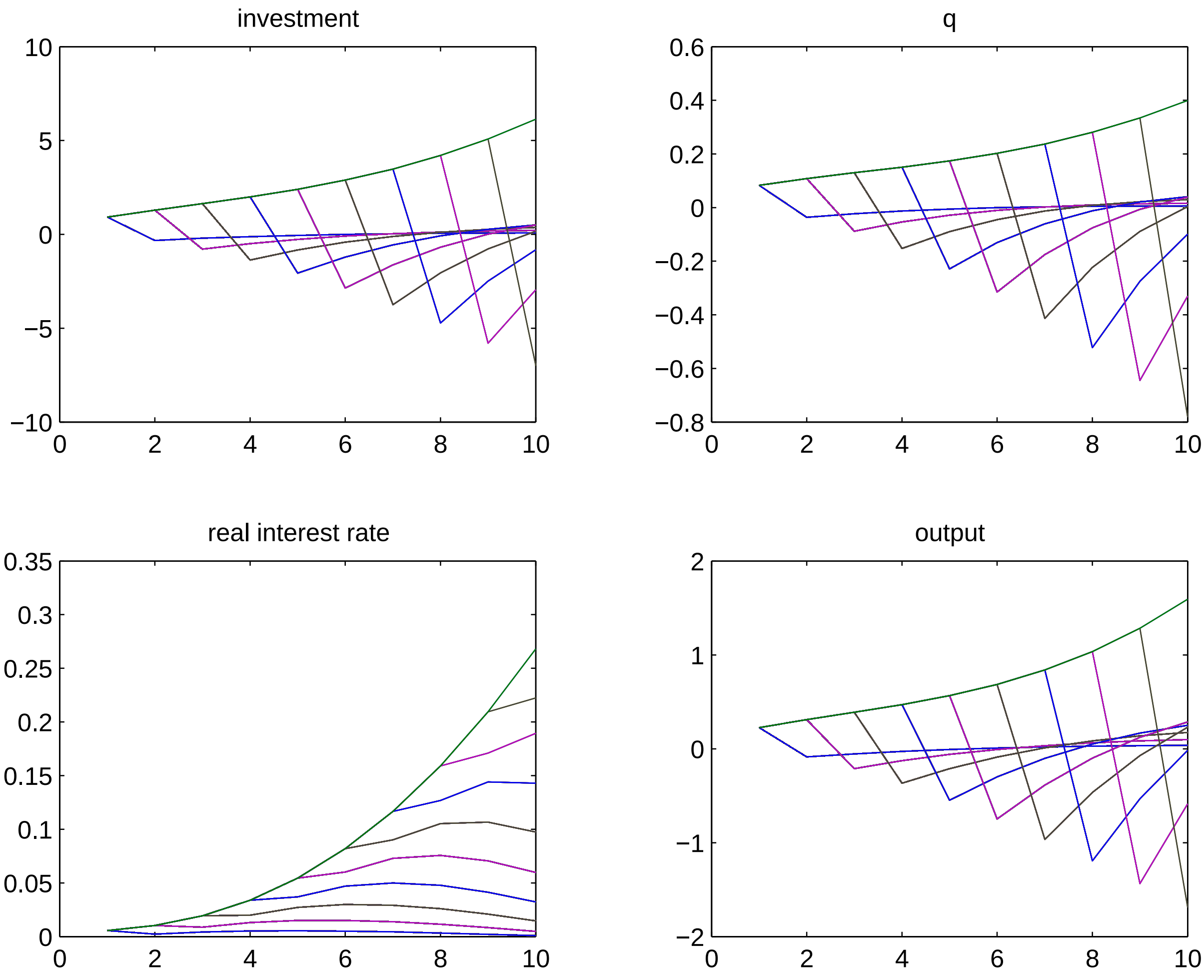

Figure 6: Impulse-response functions when there is a persistent non-fundamental shock in period 1 and the policymaker employs the IFB+y

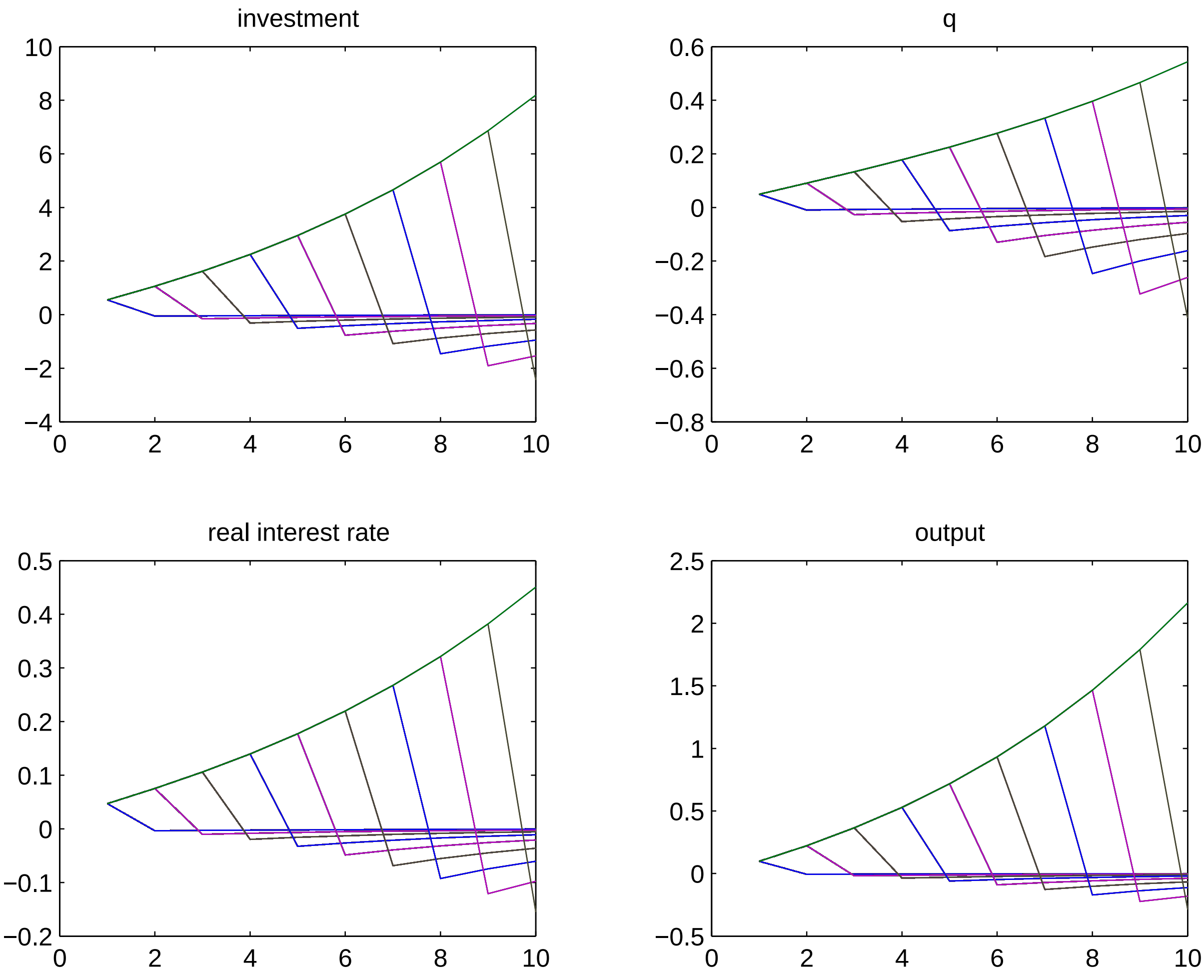

Figure 7: Impulse-response functions when there is a persistent non-fundamental shock in period 1 and the policymaker employs the IFB+y+q

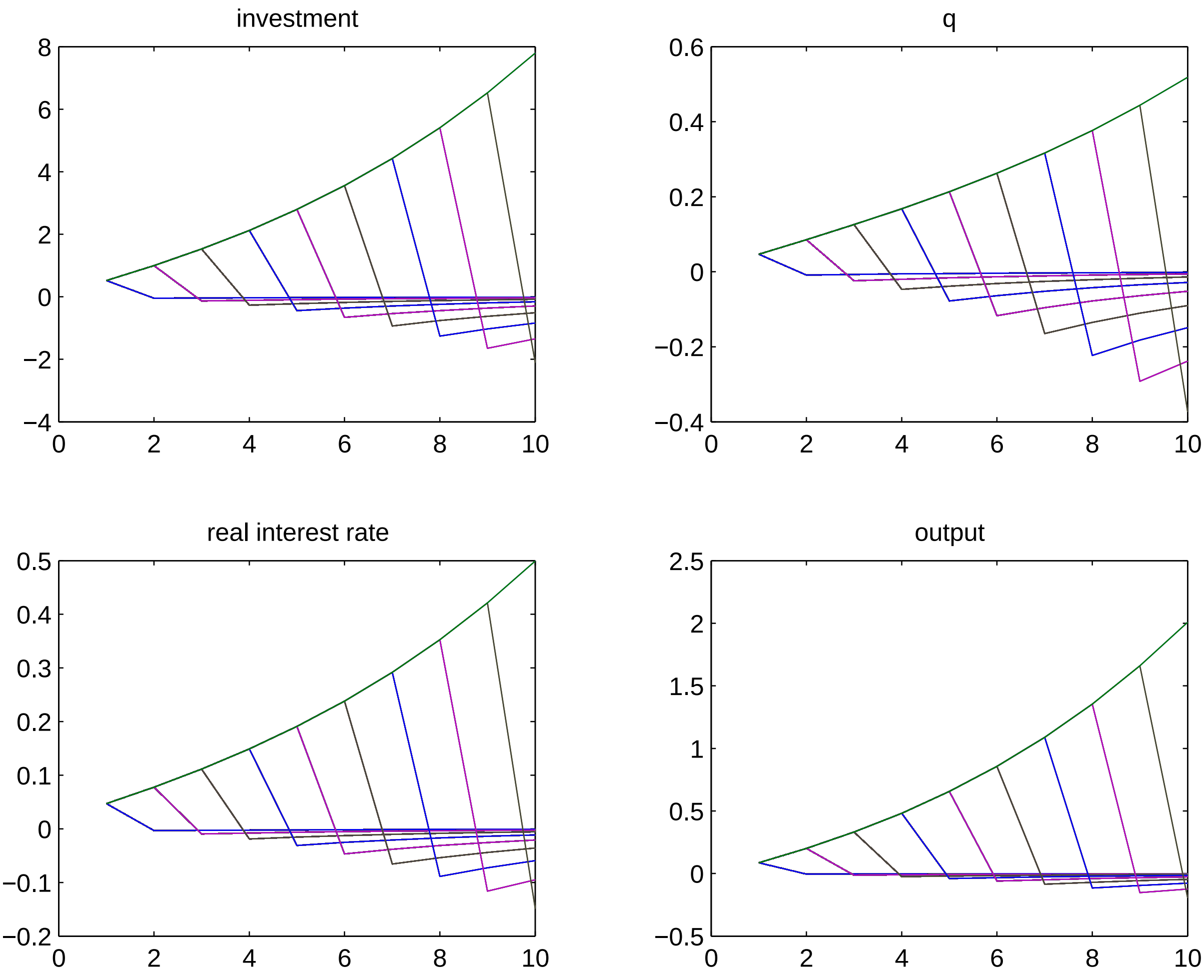

Figure 8: Impulse-response functions when there is a persistent non-fundamental shock in period 1 and the policymaker employs the aggressive IFB+y+q