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"What Should Inflation Targeting Countries Do When Oil Prices Rise and Drop Fast?"

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Western Hemisphere

"What Should Inflation Targeting Countries Do When Oil and food Prices Rise Fast?"[1]

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Abstract

After a long period of global price stability, in 2008 inflation increased sharply following unprecedented increases in the price of oil and other commodities, notably food. Although inflation remained lower and growth higher in inflation targeting countries than elsewhere, almost everywhere price stability seemed in jeopardy as consumer prices kept surging and central banks struggled to maintain expectations anchored. The rapid drop in energy and food prices that later accompanied the world slowdown helped avert the worse, but inflation stayed high in many inflation targeting countries. This paper uses a small open-economy DSGE model to design the correct monetary policy response to a protracted supply shock of the kind observed today, and explains how to choose optimal policy horizons under such shock. Using a version of the model with Kalman learning, the paper also evaluates the implications of a loss of target credibility, showing how rules must be adjusted when the authorities' commitment to low inflation has been eroded. The appropriate response to future evolutions of the price of oil, including to a large downward correction as recently observed, is also evaluated.

JEL Classification Nunbers: E52; E37; E58

Keywords: Inflation targeting, oil prices, food prices, supply shock, optimal horizon, monetary policy rules.

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[1] We thank Chris Erceg and Andy Levin for sharing the Matlab code of their 2001 JME paper.

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I. Introduction

Over the past five years, the increase in the demand of energy and food by large emerging markets, together with constraints in the production of key commodities, have pushed the price of many goods—notably oil and food—to record-high levels.

In particular, crude oil inflation, measured by the cumulative change in the spot price of a barrel of West Texas Intermediate measured in U.S. dollars, rose by almost 160 percent between 2003 Q1 and the same quarter in 2008. Both in nominal and in real (normalized by the U.S. GDP deflator) terms, this increase is about double the increase in oil prices experienced during either the first or the second oil shock of the 1970s (Table 1). Food inflation, especially of wheat and corn, has also shot up significantly over the same period. Food prices measured by the average of Reuters-Jefferies Commodity Research Bureau three key food sub indices (grains and oilseeds, livestock and foodstuff) rose by over 900 percent in the five years to 2008 Q1, partly as a result of higher demand in large emerging markets, but also as a consequence of the oil price hike—as this pushed up production costs while boosting the demand for specific food crops that serve to produce cheaper-than-oil bio-fuels.

Table 1: Oil Price Developments 1/

	50% rise date	Max log change ($) %	Max log change (real) %
1973:Q3-1974:Q1	1974:Q1	104	99
1979:Q1-1980:Q2	1979:Q3	98	85
1999:Q1-2000:Q4	1999:Q3	91	87
2002:Q1:2008:Q2	2003:Q1	180	164

1/ Table is based on the methodology in Blanchard-Galí(2007). Oil shock episodes are determined based on a cumulative change in the log price of oil of above 50%, sustained for more the four quarters.

The supply shock originating in high oil and food prices spread to headline CPI in most countries around the world, albeit to different degrees. (See IMF, 2008). Net importers of oil and food were hit most, with non-food-producing poor countries suffering a disastrous cut in real income and living conditions due to the disproportionate weight of food in their final expenditure.

Prices of oil and some base metals have dropped considerably in the second half of 2008, following the deepening of the international financial turmoil, and expectations of a global slowdown. However, with supply expected to remain limited by disruptions in producing areas, weak non-OPEC supply and the slow development of alternative fuels, the projected increase in world crude oil demand by emerging markets of 3 ¾ percent a year during 2008-

2012[2] is most likely to spur further generalized bouts of CPI inflation from ensuing increases in the price of oil and food in the years to com.

One immediate question—especially for countries with explicit inflation targets that have seen inflation rates first rise above their upper tolerance levels and then drop abruptly—is how to keep inflation anchored while minimizing the output variability costs of monetary action as inflationary, and then deflationary pressures persist.

This paper throws light on this question by answering four related questions:

- *How should interest rates be set in response to a severe but transient supply shock*? Using a small structural open-economy model with a Phillips curve that accounts explicitly for oil shocks as in Batini, Jackson and Nickell ('BJN', 2005) and Blanchard and Galí ('BG', 2007), the paper revisits the mechanics of monetary intervention in the face of a shock to supply. It then derives the optimal monetary policy response to a protracted supply shock of the kind observed today, and compares it to policies that would have been optimal for the shocks in the 1970s.

- *What is the appropriate horizon of monetary policy under a shock like this?* The methodology in Batini and Nelson (2001) is applied to impulses responses of the model to a 2007-2008-type supply shock to obtain optimal policy and feedback horizons for economies with different degrees of nominal rigidities. The analysis shows that the length of the horizon is a function of inflation volatility, agents' forward-lookingness, and target credibility.

- *How does the choice of optimal policies get affected if the target loses credibility?* Using a version of the model where agents Kalman-learn the target following a shock in target confidence from persistent target misses, the model is simulated to show how rules must be adjusted to rein in inflation expectations when the authorities' commitment to low inflation has been eroded.

- *How should central banks prepare for future developments in the price of oil?* The robustness of monetary policies to future oil shocks is evaluated using stochastic simulations where the future path for the price of oil takes the form of a Markov chain. Results indicate that the adequate policy response is rather independent of the future mean of real oil prices, but, under a symmetric target, depends on the extent by which oil prices fluctuate over a given period. Thus, continuing high oil price volatility demands bold policy rates responses going forward—quite apart from the fact that oil prices drop following a sharp increase.

[2] International Energy Agency, *Medium-Term Oil Market Report*, 2008.

The paper is organized as follows. Section 2 briefly reviews the relevant literature. Section 3 goes through some stylized facts, and then describes the model and the oil shock process. Section 4 summarizes results on optimal policy rules and optimal horizons. Section 5 revisits these results under the assumption of imperfect target-credibility. Finally, section 6 looks at how rules derived in Section 3 perform under alternative probabilistic scenarios for the price of oil. Policy implications and concluding remarks follow in Section 7.

II. Relevant Literature

The recent literature examining the relationship between oil shocks and macroeconomic output rotates around two main avenues of research. The first attempts to quantify the impact of changes in oil prices on inflation and output—a subject that has received increasing attention in recent years as economies seemed to have become more resilient to oil shocks relative to the 1970s. This research includes work by Blanchard and Galí (2007), Herrera and Pesavento (2007), Edelstein and Kilian (2007), and De Gregorio, Landrecchte and Neilson (2007), showing that the oil passthrough has declined in a number of countries due to fall in the intensity with which oil is used in production in these countries, improved monetary policy and the presence of offsetting shocks. Bernanke, Gertler, and Watson (1997, 2004) investigated how much oil price shocks have contributed to output growth. They concluded that, at most, half of the observed output declines can be attributed to oil price increases—an impact that would increase substantially if unanticipated policy shocks were anticipated (Calstrom and Fuerst, 2005). Earlier empirical work by Davis and Hamilton (2003) and Hamilton and Herrera (2004) argues that nonlinearities and asymmetries are the main features behind the observed relationship between oil and prices. Hooker (2002), on the other hand, estimates Phillips curves and tests for breakpoints to study changes in the oil price passthrough for the United States.

The second line of research attempts to identify the optimal monetary policy in response to oil shocks using DSGE models that incorporate an explicit role for oil. Among others, Medina and Soto (2005), De Fiore, Lombardo and Stebunovs (2006) and Montoro (2007), for example, look at simple policy rules. They find that oil price shocks generate a trade-off between inflation and output stabilization when oil has low substitutability in production and thus, monetary policy should partially accommodate oil-price increases.

We depart from these works in four principal ways. First, we look at both optimal and simple policy rules in the current context, and compare these to what would have characterized optimal (complex and simple) policies in the 1970s. This includes looking at how different degrees of oil pass-through affect the optimal response of the monetary authorities. Second, we focus on the time period over which inflation and output should be returned to their desired objective—a question that has been dooming today's policymakers faced by persistent oil shocks and equally-persistent deviations of inflation from target, but that so far has remained largely unanswered. Third we consider the issue of imperfect credibility—an assumption widely advocated to explain the U.S. oil-shock-driven Great Inflation of the 1970s—linking in a novel way, however, target 'disbelief' to large and highly correlated oil shocks. Finally we explore some probabilistic scenarios for the price of oil going forward, to stress out the rather isomorphic nature of policy rules under periods of heightened oil price volatility.

III. Methodology, Data and Calibration

The baseline model that we use is a small-scale, forward-looking open economy model that incorporates elements of Ball (1999), Batini and Haldane (1999), and McCallum and Nelson (1999a). The structural equations of the model are:

$$y_t = E_t y_{t+1} + \theta y_{t-1} - \sigma\left(R_t - E_t \pi_{t+1}\right) + \delta \tilde{q}_{t-1} + e_{y_t} \tag{1}$$

$$\pi_t = \alpha \pi_{t-1} + (1-\alpha) E_t \pi_{t+1} + \phi_y y_{t-1} + \phi_q \Delta \tilde{q}_{t-1} + \varphi \Delta roil_t + e_{\pi_t} \tag{2}$$

$$E_t q_{t+1} = q_t + R_t - E_t \pi_{t+1} + \kappa_t \tag{3}$$

where y_t is log output, R_t is the nominal interest rate (again, a quarterly fraction), π_t is quarterly inflation, $\Delta roil_t$ is the first difference in the log-level real price of oil, q_t is the log real exchange rate (measured so that a rise is a depreciation), and $\tilde{q}_t = \frac{1}{4}\sum_{j=0}^{3} q_{t-j}$ is a four-quarter moving average of q_t. These variables are all expressed relative to steady-state values. e_{yt}, $e_{\pi t}$, and κ_t are exogenous IS, Phillips curve, and uncovered interest parity (UIP) shocks, respectively. Our baseline assumption is that agents have full credibility in the central bank inflation target, and that they form expectations in a model consistent fashion. We discuss the implications of departures from this assumption in Section VI below.

Eq. (1) is the model's IS equation, giving y_t as a function of its expected future value, its $t-1$ lag to capture habit persistence in consumption as in Fuhrer (2000), the real interest rate, and lags of the real exchange rate. Apart from the term in q_t , this equation corresponds to the optimization-based IS function in McCallum and Nelson (1999a), and we choose parameter values based on their estimates: $\sigma = 0.2$ and an AR(1) process for e_{yt} with coefficient 0.3 and 1% innovation standard deviation. Our choice of $\delta = 0.05$ then produces the same ratio of interest rate to exchange rate coefficients in the IS curve as is used in Batini and Haldane(1999).

Eq. (2) is a quarterly version of the Ball (1999) open-economy Phillips curve, modified to allow for some forward-looking behavior. While Ball has lagged inflation appearing on the right-hand side of (2) with coefficient 1.0, we replace this with the mixed backward}forward looking term, $\alpha \pi_{t-1} + (1-\alpha) E_t \pi_{t+1}$ and calibrate α to 0.8, close to estimates in Fuhrer (1997) and Rudebusch (2000). We calibrate the coefficient ϕ_y to 0.1, the quarterly counterpart of Ball's choice and choose $\phi_q = 0.025$. We assume $e_{\pi t}$, is white noise with standard deviation 1%.

Following BJN and BG, the Phillips curve is augmented with changes in an oil price variable ($roil_t$) representing the log-level real price of oil to capture the (real) cost implications of shocks to price of oil as distinct from other supply shocks affecting inflation (the equation governing the evolution of this variable is discussed below).[3, 4] We calibrate the oil pass-through parameter to 0.02 (indicating that 100 percent increase in the real price of oil is passed through as an increase of 2 percentage points in inflation) in line with recent empirical evidence for a broad set of countries in De Gregorio, Landerreche and Neilson (2007). Since it has been argued that linear and symmetric Phillips curve specifications may misrepresent the form of the oil interaction (see Hooker, 1996, 2002) especially at time of abrupt oil price dynamics, we also experiment with higher degrees of oil price pass-through.

The exchange rate enters both the IS and Phillips curve relationships in a backward-looking manner, as a lagged four-period average. A more forward-looking specification of the model's open-economy elements would put Δq_t and $E_t\Delta q_{t+1}$ in Eq. (2). We found, however, that this scheme produced an implausibly tight and mechanical relationship between exchange rate change and inflation. Thus, we have followed Ball (1999) by only allowing q_t to enter with lags; this might be rationalized by a gradual 'pass-through' of exchange rate changes to export and import prices. While q_t enters Eqs. (1) and (2) only in a backward-looking manner, this is compensated by the fact that the exchange rate itself is a highly forward-looking variable, as Eq. (3) indicates. The shock term κ_t that produces deviations from strict UIP in (3) is assumed to be $AR(1)$ with coefficient 0.75 and innovation standard deviation 0.9%; these choices are based on our average estimates of this process using quarterly data for a variety of small inflation targeting open economies (both advanced and

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[3] As shown in BJN (2005), if the import requirement of gross output is rising at the margin and it is not possible to substitute between capital and labor inputs, on one side, and the imported input, on the other side, then the marginal cost of producing value added output will be increasing in the real price of imported intermediates, like oil. So given more general technologies than that assumed in Galí and Gertler (1999), the real price of imports will be one of the determinants of inflation in economies that employ imported material inputs for production.

[4] Although the impact of recent hikes in food prices on CPI in many countries has been large, we do not include a food price shock in the Phillips curve. This is because equation (2) is a structural pricing relationship for firms in the spirit of Galí and Gertler (1999), where π_t is interpreted to be the gross value added deflator. Even if the share of oil in production has diminished substantially over time, as documented in Hooker (1999) and BG—oil still plays a key role in production, while food plays only a negligible one, save the case of the food industry. This may change as bio-fuels—fuels like ethanol and bio-diesel, obtained through the processing of certain agricultural crops like—will take on a bigger share in energy production over the coming years. In the 2008 *International Energy Outlook* reference case, the United States accounts for nearly one-half of the rise in world biofuels production, at 1.2 million barrels per day in 2030, half of today's oil-equivalent production by use of unconventional fuels, which is also expected to grow substantially over the next two decades.

emerging markets) with floating exchange rates. The shocks in (1)-(3) are assumed to be mutually uncorrelated.

The oil variable, $roil_t$, is assumed to follow the AR(1) process: $roil_t = \rho_{roil} roil_{t-1} + e_{oilt}$. (In the baseline experiments, e_{oilt} is also assumed to be mutually uncorrelated with the other shocks in the model.) Figure 1 lends support to this evidence showing the relative stability of nominal and real oil prices in the aftermath of the 1979 shock (especially following the price correction of the early 1980s), vis á vis the oil price explosion of the 2000s. Thus, to contrast the pre-2000 oil shock low inflation environment with the current oil boom, we experiment with two different measures of the autoregressive coefficient ρ_{roil}: a smaller coefficient (0.71), capturing the relatively stable oil price dynamics over the 1980s and 1990s; and a larger coefficient (0.99) capturing the rather explosive oil price dynamics since 2002.[5] Estimates indicate that oil inflation was not only less inertial, but also less volatile over the 1980-1990 period than in the 2000s (the standard deviation of the dependent variable is 0.2 in the 1980-1990 sample, compared with 0.4 in the post-2002 period). Thus, we account for lower-higher variance in our experiments accordingly.

IV. Optimal Policy Responses and Optimal Horizons to a 2000s-Type Supply Shock

A. Optimal Policy Responses under a 2000s-Type Oil Shock

What is the optimal response of a central bank to an oil shock of the magnitude of the shock seen in the 2000s? In this section we derive two types of optimal responses: a complex optimal monetary policy rule, and a simple monetary policy rule á la Taylor. The complex rule is de facto an inflation-targeting rule á la Rudebusch and Svensson (1999), where the welfare function penalizes inflation departures from a target, and policy is thus set according to the ensuing optimal rule. The simple rule reflects a second definition of inflation targeting used in work by Batini and Haldane (1999), McCallum and Nelson (1999b), and others. This views targeting expected future inflation simply as setting the policy instrument in response to deviations of future inflation from target.

To derive the complex optimal rule, we follow King and Wolman (1999) by augmenting the model's structural equations with the policymakers' first order conditions for optimality, and solving the resulting system of expectational difference equations. The Lagrange multipliers for the policymakers' problem form part of the state vector in this commitment solution.

[5] The smaller coefficient results from fitting an AR(1) to the difference between the log level of PPI of crude oil and the log of the US GDP deflator over the period 1986 Q1-2001 Q4. The larger coefficient emerges estimating the AR(1) over a 2002 Q2 – 2008 Q2 sample.

By contrast, in the spirit of Taylor (1993, 1999), the simple rule is considerably more parsimonious, and is modelled as:

$$R_t = \gamma R_{t-1} + \psi_\pi \left(E_t \pi_{t+k} - \pi^*\right) + \psi_y \Delta y_t \qquad (4)$$

where R_t is the short-term nominal interest rate, $E_t\pi_{t+k}$ is the period t forecast of inflation in $t+k$, Δy_t is real output growth, π^* *i*s the inflation target, and ψ_π, $\psi_{\Delta y} > 1$. We use the growth of output instead of the output gap to ensure that the rule is 'operational', as suggested by McCallum (2001). To carry out the comparison with the complex, fully optimal rule, we consider simple 'optimized' rules. In this case, the parameters ψ_π, $\psi_{\Delta y}$ and γ are those that minimize the policymaker's loss function for each *k*.

Throughout we assume that policymakers wish to prevent deviations of inflation from target and departures of output from potential. We also assume that policymakers dislike instrument volatility. For computational convenience, these preferences are represented by a quadratic loss function in which the loss was quadratic in asymptotic variances of inflation deviations from target and output deviations from potential. This is often used as a metric for capturing policymakers' preferences in studies that attempt to evaluate the trade-off between inflation variability and output variability under alternative specifications of the interest rate rule (see Taylor, 1999). In the optimization exercises used to derive optimal policy horizons, this is the function that is being minimized. And when we derive optimal feedback horizons by comparing the performance of rules like (4) for various *k*s, this loss function is used to compute welfare losses in all experiments. Algebraically, the loss function is given by:

$$L_t = \sum_{j=0}^{\infty} \beta^j \left[\lambda_\pi \left(4 * \pi_{t+j} - 4 * \pi^*_{t+j}\right)^2 + \lambda_y \left(y_{t+j} - y^T{}_{t+j}\right)^2 + \lambda_R \left(4 * R_t\right)^2\right] \qquad (5)$$

where β is the discount factor, $4^*\pi_{t+j}$ is annualized quarterly inflation, π^*_t is the inflation target, y_t is log output, $y^T{}_t$ is log capacity output, and where λ_y, λ_π and λ_R, denote the weights assigned to inflation deviations from target, output deviations from potential, and volatility in the nominal interest rate, respectively. We set $\beta = 0.99$, $\lambda_y = \lambda_\pi = 1$, and $\lambda_R = 0.5$, so that inflation and gap variability are penalized equally. The interest rate volatility term, which rules out extremely large movements of the instrument in response to shocks, receives a penalty half that of the other terms. These weights are similar to those used in Rudebusch and Svensson (1999).

In the simple 'optimized' rules, the vector of 'optimised' coefficients $\tilde{x} = \left(\gamma, \psi_\pi, \psi_y\right)$ is chosen to minimize L_t by employing a simplex search method based on the Nelder–Mead algorithm.

Complex optimal and simple optimized rules are derived for the two parametrization of the oil price process: the 'stable' oil regime of the 1980s-1990s and the 'quasi-explosive' regime of the 2000s. The upper row of charts in Panel 1 plots impulse responses of real output, inflation, the nominal interest rate and the exchange rate to a unit oil shock when the central bank follows the complex rule. Under our parametrizations, the shock resembles in each case duration and size of the shocks in the two oil regimes. The lower row of charts in Panel 1 does the same assuming that the central bank instead follows the simple 'optimized' rule (note that the horizon k is also chosen to minimize the policymakers' loss function). Finally, Panel 2 repeats the exercise, but using a calibration of the oil shock and of the oil pass-through that replicates the 1970s. All panels also plot the response of inflation, the output gap and the nominal interest (annualized) in the case when we set the oil passthrough to its estimated 1970-1980 level (0.1).

Impulse responses suggest some interesting facts. First, when the central bank uses the optimal complex rule, the quasi-explosive regime of the 2000s resembles closely what happened during the oil shocks of the 1970s. When the oil pass-through is set to the low recent estimate (0.02), inflation increases accordingly only by 15 of a percent in both cases, while output falls below potential and remains there for very prolonged period. By contrast, under the 'stable' regime output goes back to potential in less than two years, with inflation staying equally contained. Second, under simple rules, responses exhibit analogous patterns, but tend to be considerably more volatile. In addition, output never remains longer than a year below potential, although in all scenarios, it behaves significantly more cyclically. Throughout, the real interest rate turns positive, as nominal rates grow on average around 5 times more than inflation.

Finally, impulse responses obtained when we parametrize the shock to the 1970s regime, but setting the oil pass-through parameter to a high level (0.1, in line with average estimates of the parameter between 1970 and 1980 by De Gregorio, Landerreche and Neilson, 2007) show what can happen in economies with oil-intensive production technologies, like some emerging markets today, faced by a shock similar to the recent one. Under a same-sized shock, and the complex rule, inflation increases three times as much than under a lower pass-through parametrization, and output slides well below what found in experiments obtained using parametrizations on recent data, as interest rates have to rise three times as much to contain inflationary pressures. Using simple rules, the story is analogous, although inflation is more muted as interest rates jump up faster and output drops sooner. Once more, in all cases, results suggest that it is optimal to raise nominal rates to the point where real rates become strongly positive. It is precisely the failure to ensure this following the recent oil shock in several emerging market countries that has caused inflation to rise and inflation expectations to become unanchored in mid-2008.

Table 2 reports associated key welfare statistics for the two oil regimes, and, for comparison, for the rules applied to a 1970s equivalent-type shock. The table also shows how results get affected when we set the oil pass-through parameter to its estimated 1970-1980 average (0.1) instead of the value it takes when estimated on more recent data (0.02).

Table 2: Welfare Statistics—Various Oil Regimes

'Stable' Oil Regime (1986 Q1–2001 Q4)					
Rule Type	*AsyVar(y)*	*AsyVar(π)*	*AsyVar(R)*	*AsyVar(q)*	*Loss*
Complex	0.27	0.37	0.011	0.34	2.27
Simple	1.55	0.34	0.002	2.23	3.30
'Explosive' Oil Regime (2002 Q2–2008 Q2)					
Rule Type	*AsyVar(y)*	*AsyVar(π)*	*AsyVar(R)*	*AsyVar(q)*	*Loss*
Complex	0.26	0.36	0.011	0.37	2.12
Simple	1.55	0.34	0.002	2.23	3.30
'1970s-Shocks' Oil Regime (1970 Q2–1980 Q2)—Low Passthrough					
Rule Type	*AsyVar(y)*	*AsyVar(π)*	*AsyVar(R)*	*AsyVar(q)*	*Loss*
Complex	0.27	0.37	0.011	0.85	2.19
Simple	1.55	0.34	0.002	2.23	3.30
'1970s-Shocks' Oil Regime (1970 Q2–1980 Q2)—High Passthrough					
Rule Type	*AsyVar(y)*	*AsyVar(π)*	*AsyVar(R)*	*AsyVar(q)*	*Loss*
Complex	0.38	0.58	0.017	3.98	5.47
Simple	1.55	0.34	0.002	2.23	3.30

There are three main results. First, as expected, results indicate that the complex rule is more efficient at stabilizing the inflation, output gap and interest rate volatility objectives than simple rules—also reflected in the lower volatility of impulse responses under the complex rule. It follows that the loss under optimal rules is on average 33 % smaller than under simple rules. However, when we raise the oil pass-through in the 1970s' scenario, volatilities and the loss under the optimal rule shoot up relative to when simple rules are used, becoming up to 40 percent higher than in the low pass-through scenario. That is because under the complex rule it becomes optimal to accommodate in part inflation volatility in order to avoid a more recessionary outcome—something that the simple rule is less capable of trading off being structurally more rigid.

Second, feedback parameters in the simple rule call in all cases for a *strong* response to the inflation gap and a value of the interest rate smoothing parameter larger than one to ensure a determinate rational expectations equilibrium as found in Rotemberg and Woodford (1999) ($\psi_\pi = 4.55$, $\psi_{\Delta y} = 0.02$, and $\gamma = 1.15$, respectively).

Third, asymptotically, the variability (and thus the loss) under simple rules are very similar up to the second decimal place, as are optimized coefficients for the simple rules under the various oil regimes. The finding that coefficients optimized across different oil regimes are virtually identical makes sense.[6] The loss function is proportional to the variance of the only shock we have (the shock to the real price of oil), so by changing the persistence we are maximizing the same value function times a constant. Formally, if we have a value function $V(\psi_m, \sigma^2)$ where ψ_m is a policy parameter in the simple rule and σ^2 is the variance of the supply-side shock, then with different persistence it becomes $kV(\psi_m, \sigma)$ where k is a constant. Then argmax_ ψ_m $V(\psi_m, \sigma^2)$=argmax_ ψ_m k $V(\psi_m, \sigma^2)$, in line with our findings. Since differences in the variance of the shock are tiny, and filtered through a very small oil pass-through parameter, the variance of inflation is hardly affected. Indeed, as we bump up the pass-through parameter to mimic full pass-through, both optimized coefficients in simple rules, asymptotic variances and the loss start to diverge more markedly. Optimized parameters also differ if we add other shocks as we will see in the section where we examine the case of imperfect target credibility.

B. Optimal Horizons for a 2000s-Type Oil Shock

What is the best horizon for monetary policy under an oil shock like today's? There are two key ways of thinking about an optimal horizon for inflation targeting, depending on the way that inflation targeting is modeled. If policy is represented, for instance, by a simple feedback rule on expected future inflation like (4), one way is to think of it as the best horizon for which the authorities should form a forecast for inflation to use in the rule. If, instead, policy is represented by an optimal rule for the instrument, the optimal horizon can be thought of as the time at which inflation should be on target in the future when the authorities aim at minimizing their loss function, and a shock occurs today. In what follows, following Batini and Nelson (2001), we refer to the first kind of horizon as the "optimal feedback horizon" (OFH) and to the second kind as the "optimal policy horizon" (OPH). In practice, this usually involves targeting the conditional forecast of inflation the inflation rate expected to prevail in the future given presently available information, rather than current inflation.

[6] IRFs are different because the initial impulse depends on the persistence of the shock. However their shape is identical. We thank Paul Levine for pointing these considerations out to us.

Choosing the Optimal Policy Horizon

In line with Batini and Nelson (2001), we define the optimal policy horizon (OPH) as the time at which it is least costly, for a given loss function, to bring inflation back to target after a shock. More intuitively, the OPH is the horizon-analogue of the optimal speed of disinflation, i.e. the optimal time required for the dissipation of a shock. Operationally, the OPH is given by the number of periods after a shock when inflation is back on target under an optimal rule.

Below, we derive OPHs for various parametrization of our model, under alternative calibrations of the oil shock. In this respect, an important question is how to interpret the idea of being 'on target'. Since, in these models, inflation tends to fluctuate around target before settling definitely on a particular number in the wake of a shock, a point target (e.g. 2 percent) is not very meaningful. Instead, we consider OPHs as referring to target ranges, so the OPH is the time when inflation returns to a specified band around the target. This is not an argument for target ranges rather than point targets, but a device to make model experiments useful.

As in Batini and Nelson (2001), we use two operational definitions of an OPH: an absolute and a relative horizon concept. The first definition interprets an OPH as the number of periods ahead, k, at which inflation has returned permanently to within a target range of ±0.01 percentage points, following a shock today. The second definition is based on what fraction of a shock's effect policy has succeeded in eliminating. Specifically, it interprets the optimal policy horizon as the number of periods ahead, k, at which 90% of the peak effect of the shock on inflation has been extinguished. We denote OPHs under the absolute criterion by k_A*, and OPHs under the relative criterion by k_R*. Since, typically, both k_A* and k_R* will vary according to the nature and DGP of the economic shock, we compute OPHs under the two criteria for different calibrations of the oil shock.

Table 3 gives OPHs for each model parametrization under the two definitions (k_A* and k_R*).

Table 3: Optimal Policy Horizons Under Alternative Oil Regimes

Oil Regime	k_A*	k_R*
'Stable'	6	11
'Quasi-Explosive'	3	28
'1970s'	3	20
'1970s with High Pass-through'	10	12

Throughout, results under the absolute criterion, indicate that the minimum 'optimal' horizon after which to return inflation to target is 1½ years (under either the 'stable', 'quasi-explosive' and '1970s' oil regimes), while the maximum is 2½ years (under the '1970s high pass-through' regime), depending on the extent by which the oil shock is passed through to inflation.

Apart from the case of 'high pass-through' where inflation undershoots and overshoots the target several time, requiring a k_A*, as long as 10 quarters, the optimal horizon under the absolute criterion is less than a year because the response of inflation under the AS shock is substantially smaller in the initial period because the interest rate can contemporaneously affect inflation, in contrast with VARs where the effect is lagged by construction. So under our baseline weight combination, the optimal policy cuts the effect on inflation of the supply innovation from (what would have been) 0.02% to 0.01%. However, because of the inherent persistence of inflation in the aggregate supply specification employed here, and despite the partial forward-looking behavior in the IS function, it takes three quarters to be dragged back to target under the k_A* criterion, with undershooting then preventing inflation from settling back at target for eleven to twenty quarters under the k_R* criterion. The 'stable' regime requires a longer horizon because, although less autocorrelated, inflation was more volatile over this period, and so are impulse responses from our model.

Results under the relative criterion seem to demand a considerably more gradual stabilization strategy, mostly because this criterion is considerably more exacting when the initial impact of the shock is small in magnitude (for example, in the case of the 'quasi-explosive' oil regime, the relative criterion computes the horizon on the basis of the requirement that inflation is returned permanently below the level of 2×10^{-4} of a percent).

How do results get affected if agents form their inflation expectations in a more forward-looking fashion, for example as would result by setting the α to 0.3, instead of the baseline assumption of 0.8? This could happen in a situation where inflation expectations are not closely tied to past inflation, because—for example—there is very little inflation indexation in price and wage contracts. Table 4 recalculates optimal horizons for this calibration of the α parameter.

Table 4: Optimal Policy Horizons Under Alternative Oil Regimes (α=0.3)

Oil Regime	k_A*	k_R*
'Stable'	6	6
'Quasi-Explosive'	6	10
'1970s'	6	11
'1970s with High Passthrough'	10	10

Under this experiment the length of the optimal horizon in the 'stable' oil regime is unaffected. However, and perhaps contrary to expectations, in this case optimal horizons under low pass-through double in length for the 'quasi-explosive' and '1970s' regime, since inflation drops more under the initial peak after the shock, and thus takes longer to re-enter the very small targeted range under this criterion. By contrast, in all cases, optimal horizon under the relative criterion shortens, as impact responses of inflation are slightly larger so that it takes proportionally less for the shock to evaporate in relative terms.

One final question, that is particularly relevant in examining the right policy response to the oil shock of the 2000s, is what would be the correct horizon for policy in case several oil shocks followed, like from a sustained increase in the price of oil over time. We do not experiment explicitly with this scenario here, but following the logic of this exercise, it is reasonable to expect that this would lead to 'accumulation and overlapping' of impulse responses that in turn would push forward the date in the future, relative to the first shock, when it is optimal to have inflation return to the target range. For example, in the case of four consecutive quarterly oil shocks of unit magnitude, inflation would have to go back to target from a much higher level, peaking at quarter 4 instead of 2, as currently happening under a unique unit shock. This would presumably entail a much longer optimal horizon, that is a horizon at least 2-3 times longer the horizon that is optimal under a unit shock.

Choosing the optimal feedback horizon

OPHs are optimal horizons obtained assuming that the policymakers followed a complex optimal rule—a function of the entire state vector. Suppose instead that the policymakers operate via a simple rule that involves changing the policy instrument in response to deviations of expected inflation from its target value, as in Eq. (1). By suitable choice of the feedback horizon, this rule can be designed so as to incorporate monetary transmission lags. In particular, in the case where lags hinder control of current inflation, the date of the inflation forecast in the rule can be chosen so that inflation at that date is indeed affected by monetary policy.

When inflation targeting is implemented through rules like Eq. (4), the best *k*-period- ahead forecast of inflation will be the one that minimizes the costs of inflation control according to loss function (5). As explained in Section 2 above, we define this horizon as the optimal feedback horizon (OFH). Two things are worth noting here. First, we consider the OFH to be the k that minimizes (5) when the feedback coefficient in Eq. (4) is itself optimally chosen. That is, the choice of the optimal *k* is conditioned on $\tilde{x}$ being optimal. Second, in contrast with the previous section, the optimal horizon is not a concept that can be bracketed by a range. Rather, it can only be a discrete point (i.e., the best *k* at which to form the forecast of inflation that enters the rule).

Table 5 summarizes the results on OFHs. To obtain them, we contemplated values of *k* of (0-12) that is, up to three years ahead. Table 5 indicates that under all parametrizations of the oil shock, the model favors a zero feedback horizon, that is a current-looking policy rule. This is in line with findings in Batini, Levine and Pearlman (2006, 2007), who find that responding to expected future rather than current inflation leads to multiple stable solutions. Note that a zero feedback horizon does not imply that inflation should return to target in no time. For example, under the optimal zero feedback horizon for the 'stable' oil regime, inflation would return to target within 4 calendar quarters based on the rule's optimally chosen feedback parameters (corresponding quarters-ahead return times for inflation under oil shocks in the 'quasi-explosive', '1970s' and '1970s with high pass-through' are 4, 2, and 4, respectively).

Table 5: Optimal Feedback Horizons Under Alternative Oil Regimes

Oil Regime	k_F*
'Stable'	0
'Quasi-Explosive'	0
'1970s'	0
'1970s with High Passthrough'	0

V. Optimal Rules Under Imperfect Credibility

Perhaps the most worrisome problem facing monetary policymakers during the past and current oil shocks has been that as inflation accelerates following higher energy costs, agents become pessimistic about future inflation and expectations of future inflation worsen. In the attempt to preserve the value of their future real profits and income, agents incorporate their pessimism into new price and wage contracts, so that inflation expectations translate into higher actual inflation, propagating the first round effects of the oil shock. Inflation expectations are then said to have become "unanchored" from the inflation target.

In this section we examine how a loss of credibility in the target (from above-target inflation expectations) affects the performance of the policy rules derived in the previous section under the assumption of full credibility. In addition, we study how rules should be modified to account for imperfect credibility and second round effects.

To model imperfect credibility we deviate from the expectational assumption of the baseline model described in the previous sections. Following Erceg and Levin ('EL', 2003), we instead assume that agents know the model—including the central bank policy rule, its parameters and the *announced* central bank inflation target—and can infer the current value of the inflation target. However, they cannot observe directly the underlying components of the target, and face a signal extraction problem to predict future values of the inflation target.

Like in EL, the target is the sum of a constant, steady-state rate of inflation and two zero-mean stochastic components, i.e.:

$$\pi^*_t - \bar{\pi} = \left(\pi_{pt} - \bar{\pi}\right) + \pi_{qt} \tag{6}$$

In turn, the stochastic components follow a VAR(1) process like:

$$\begin{bmatrix} \pi_{pt+1} - \bar{\pi} \\ \pi_{qt+1} \end{bmatrix} = \begin{bmatrix} \rho_p & 0 \\ 0 & \rho_q \end{bmatrix} \begin{bmatrix} \pi_{pt} - \bar{\pi} \\ \pi_{qt} \end{bmatrix} + \begin{bmatrix} \varepsilon_{pt+1} \\ \varepsilon_{qt+1} \end{bmatrix} \tag{7}$$

We calibrate ρ_p and ρ_q such that shocks to the $\pi_p - \bar{\pi}$ component of the target take a long time to fade away ($\rho_p = 0.9$), while shocks to the π_q component dissipate much faster ($\rho_q = 0.05$). To mimic the current situation of "target disbelief" following a large oil shock and the associated large inflationary effect on impact, we assume that although both innovations ε_{pt} and ε_{pq} are white noise with variances v_1 and v_2 respectively, the persistent inflation target innovation ρ_p is correlated with the oil shock with cross-correlation coefficient equal to 0.3. In other words, every time that an oil price increase generates a sustained inflationary pressure and inflation deviates persistently from target, agents need to figure out whether the deviation is very transient or is about to persist, following a protracted, but *unannounced*, shift away of the central bank from its long-run target.

As in EL, we assume that agents use the Kalman filter to derive an optimal solution to the signal extraction problem. Defining, as they do, $\tilde{z}_t = \left[\left(\pi_{pt} - \bar{\pi}\right)\pi_{qt}\right]'$ we augment the model with the equation specifying the recursive representation of the unobserved components:

$$E_t\tilde{z}_t = FE_{t-1}\tilde{z}_{t-1} + L_{gain}\left(\pi^* - \tilde{h}FE_{t-1}\tilde{z}_{t-1}\right) \tag{8}$$

Where from (7), $F = \begin{bmatrix} \rho_p & 0 \\ 0 & \rho_q \end{bmatrix}$ and $\tilde{h} = \begin{bmatrix} 1 & 1 \end{bmatrix}$. The Kalman gain matrix is then given by FL_{gain}, where L_{gain} is the matrix according to which agents 'learn' from their $\pi^* - \tilde{h}FE_{t-1}\tilde{z}_{t-1}$ forecast error in predicting π^* one period ahead. Given L_{gain} (that we calibrate in line with EL estimates on U.S. data) and the expectation at time t of $\tilde{z}_t$, the J-period-ahead optimal forecast of the inflation target then corresponds to:

$$E_t\pi^*_{t+J} = \bar{\pi} + \tilde{h}F^J E_t\tilde{z}_t \tag{9}$$

Panel 5 plots impulse response functions to a unit variance oil shock under imperfect credibility, in the case of the 'stable' oil regime of the 1980s-1990s and in today's (2000s) case. As expected, when agents start doubting about the commitment to the announced inflation target following protracted departures from it, inflation delays significantly in returning to its long-term goal, even if the central bank raises the nominal interest rate promptly and sharply to generate sustained positive real rates. Under a same-sized shock as that used to generate impulse responses for Panels 1 and 2, inflation now increases up to 50 times as much even assuming that the oil pass-through is low, generating a de facto almost full oil pass-through (that is if oil grows 100 percent inflation peaks at between 83 and 86 percent just a few quarters after the shock). It becomes much more costly to rein in inflationary pressures from the shock and, following the necessary spike in interest rates to stabilize prices, the output gap drops three times deeper relative to the full credibility case, and after growing temporarily above potential as higher expected inflation under target disbelief reduces temporarily the cost of capital and boosts production.

Another noteworthy inference from looking at the impulse responses is that the shock to target credibility largely dominates differences in the oil shock itself—such that all regimes exhibit quasi-identical paths for the return of inflation to the long-run target, and likewise, for output return to potential and interest rates to their pre-shock(s) level.

In the case in which credibility in the target is less than perfect, the horizon at which is efficient according to the central bank's loss function to rein in inflation lengthens enormously, suggesting a ten-year period for inflation to be back on track (although the path suggests, ignoring specific criteria, that after 2 ½ years inflation's deviation from target should already be below ½ of a percent.) There are two important corollaries to this result. First, in practice the cross-correlation between the shock to credibility and the oil shock is endogenous to the length of the target miss. This implies that choosing a shorter horizon—reacting more aggressively early on—might de facto contain the magnitude of the overall shock, reducing output variability costs of the disinflation. Failure by many central banks to act promptly during the recent shock explains the subsequent difficulties experienced by many in containing a ratcheting up of inflation expectations. Second, that central bank communication is crucial at time of target misses. Explaining the central bank's strategy on how it will return inflation to target and over which horizon—with possible updates in case of repeated shocks—fully and transparently, may have real benefits by minimizing target disbelief. Those central banks that have downplayed the shock, by interpreting its impact on inflation as temporary, or that shifted focus on core inflation measures to stress the stability of underlying inflation have indeed scored worse than banks that communicated more frankly and transparently with markets.

VI. Bracing for Future Shocks

As a final experiment, we study how should policy prepare for future evolutions of the oil shock. Following a long ascent begun in early 2002, in December 2008, oil prices plunged to a twenty-month low (below US$ 40 per barrel), in response to concerns of a global economic slowdown, and subsiding fears earlier in September of potential disruptions of U.S. oil supplies during the Northern Hemisphere summer hurricane season. The correction could herald further downward adjustments in oil prices, also from a contraction in demand in response to higher prices and substitution effects, like it happened in the early 1980s in response to the 1970s' shocks. An alternative, and perhaps more plausible scenario is that the recent moderation in oil prices will not last long, and that inflationary pressures from oil excess demand—especially in China and India—will soon reappear, possibly with renewed strength.[7] This looks particularly likely considered that the very recent slide in oil prices have posed further threats to supply, with many large oil exploration and extraction expansion projects put on hold either because the ensuing sudden drop in expected profitability (e.g. Canada' oil sands need an oil price just shy of US$ 90 per barrel to develop while reducing the environmental impact) or because many depend heavily on debt to finance operations (especially highly leveraged companies in locations such as Russia and the Caspian).

A back-of-the-envelope calculation based on estimates by the Energy Information Administration of global demand and supply growth over the past 5 years, indicates that, given supply's medium-term trends, every 1 quadrillion Btu increase in the world demand for liquid fuels produced an US$5 increase in oil prices. At current projected demand growth rates, this would imply an additional *increase* in the price of crude oil of about US$ 90 over the next 5 years, other things equal.

To explore how monetary should adjust to alternative oil price scenarios, we simulate the model stochastically, assuming three competing future paths for the price of oil. In each scenario, over the next 12 quarters the price of oil behaves as a Markov chain and can either: jump at the current 2008 Q2 quarterly average level and remain there (Scenario 1); jump to 2008 Q2 level and then to a higher level (Scenario 2); jump to 2008 Q2 level but then revert to a level than is in-between the 2002 Q1 and the 2008 Q2 quarterly average levels (Scenario 3); and finally, Panel 4 displays the shape taken by the real (log) price of oil and of the first difference of the real (log) price of oil across 100 simulations under the three alternative scenarios.

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[7] In the EIA's 2008 IEO reference case, prices ease somewhat in the medium term, as anticipated new production—both conventional and unconventional (in Azerbaijan, Brazil, Canada, Kazakhstan, and the United States, for example)—reaches the marketplace. Ultimately, however, markets are expected to remain relatively tight. In nominal terms, world oil prices in the EIA's 2008 IEO reference case decline from current high levels to around $70 per barrel in 2015, then rise steadily to $113 per barrel in 2030 ($70 per barrel in inflation-adjusted 2006 dollars).

The Markov chain used to generate competing stochastic paths for the real price of oil has the following properties: it assumes two states ('low' and 'high') for the mean and standard deviation of real oil price. The stochastic process starts in the low state with a low switch probability (0.02) but after the probabilistic switch happens, it assumes a high (0.9999) probability of remaining in the higher state. The high state is maintained for 12 quarters after which the process follows one of the three scenarios above for the remainder of the simulated quarters. The standard deviations are the historical 1986-2001 value for the low state and 2002-2008 values for the high state, with reversion to the low state for the three scenarios above.

Table 6 shows the simple rule's coefficients that minimize the central bank's loss function in the various scenarios.

Table 6: Optimized Feedback Coefficients Under 3 Alternative Future Oil Scenarios

	ψ_{π}	$\psi_{\Delta y}$	γ
Scenario 1 (L-H-H)	3.61	0.052	1.15
Scenario 2 (L-H-HH)	4.13	0.048	1.14
Scenario 3 (L-H-M)	4.12	0.049	1.10
Scenario 3A (L-H-L)	4.00	0.050	1.15
Memo: unit shock	4.55	0.020	1.15

Four important results emerge looking at Table 6. First, in all cases, the central bank needs to react strongly closing quickly the inflation gap. Second, as in the unit shock case, over-smoothing is necessary to ensure determinacy of equilibria and to strengthen the deterrent effect of the policy response. Feebacks on output growth are small, as output gap stabilization is a concern but less so in growth terms. Importantly, results indicate that, under symmetric targets, there is no huge difference in the optimal central bank reaction function derived under Scenario 2 and 3A. This implies that the central bank should behave aggressively (that is responding strongly to the deviation of inflation from target) even following a drop in the real price of oil—as long as the volatility in inflation stays high.

VII. Concluding Remarks and Policy Implications

The oil shock of the 2000s is close in size and nature to the combined shocks of the 1970s. Thus, the optimal response of inflation targeting central banks should be similar to what would have been optimal then: an aggressive increase in real interest rates, meant to close the inflation gap over the minimum efficient policy horizon. Repeated rates rise in nominal terms would ensure determinacy and strengthen the anti-inflation signaling of monetary authorities.

It is precisely the failure to ensure this following the recent oil shock in several emerging market countries that has caused inflation to rise and inflation expectations to become unanchored.

An additional key result of the analysis is that under a symmetric inflation target, policy should remain aggressive even if the adverse supply shock is followed by a favorable one, as in the present case, since the central bank objective ultimately consists in minimizing deviations (in absolute terms) from the long-run objective.

In all cases, results show that it takes time to rein in a shock of this magnitude, and years to rein at minimum output gap variability costs consecutive shocks of the same magnitude. We also find that a loss in target credibility worsens dramatically the policy dilemma, requiring much higher interest rate gyrations and, thus, larger output gap losses for inflation to be controlled. Results also suggest that reacting more aggressively early on—might de facto contain the magnitude of the overall shock, reducing output variability costs of the disinflation. Failure by many central banks to act promptly during the recent shock explains the subsequent difficulties experienced by many in containing a ratcheting up of inflation expectations. Second, that central bank communication is crucial at time of target misses. Explaining the central bank's strategy on how it will return inflation to target and over which horizon—with possible updates in case of repeated shocks—fully and transparently, may have real benefits by minimizing target disbelief. Those central banks that have downplayed the shock, by interpreting its impact on inflation as temporary, or that shifted focus on core inflation measures to stress the stability of underlying inflation have indeed scored worse than banks that communicated more frankly and transparently with markets.

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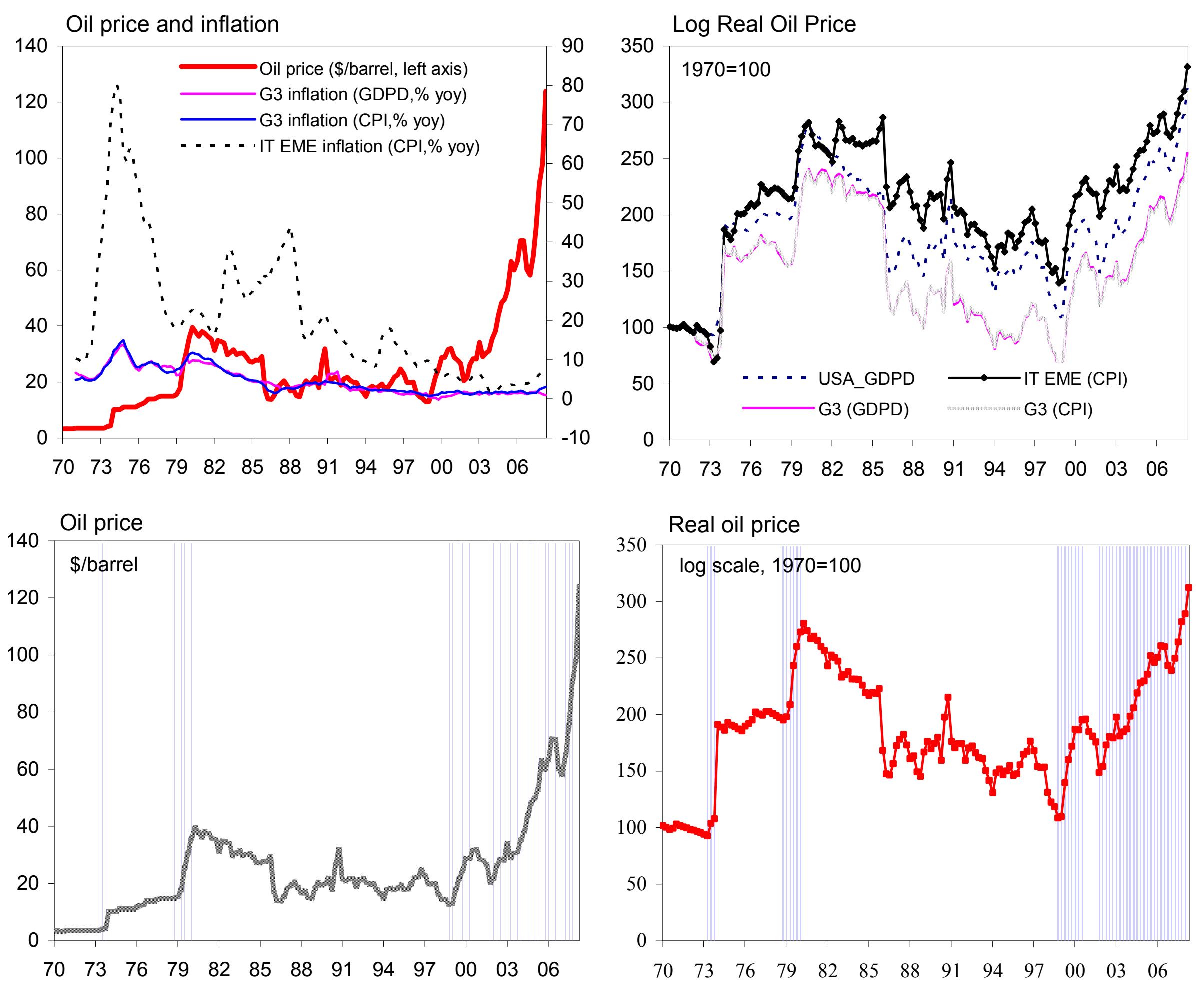
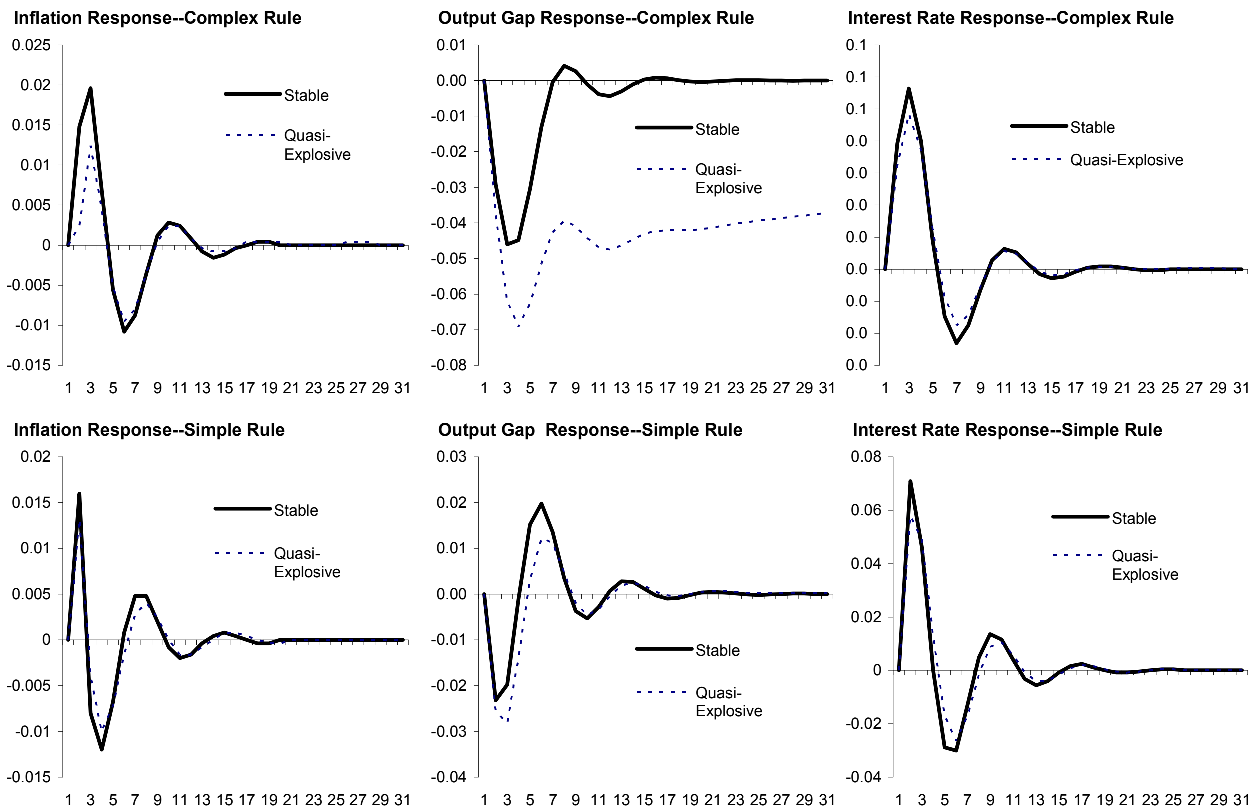
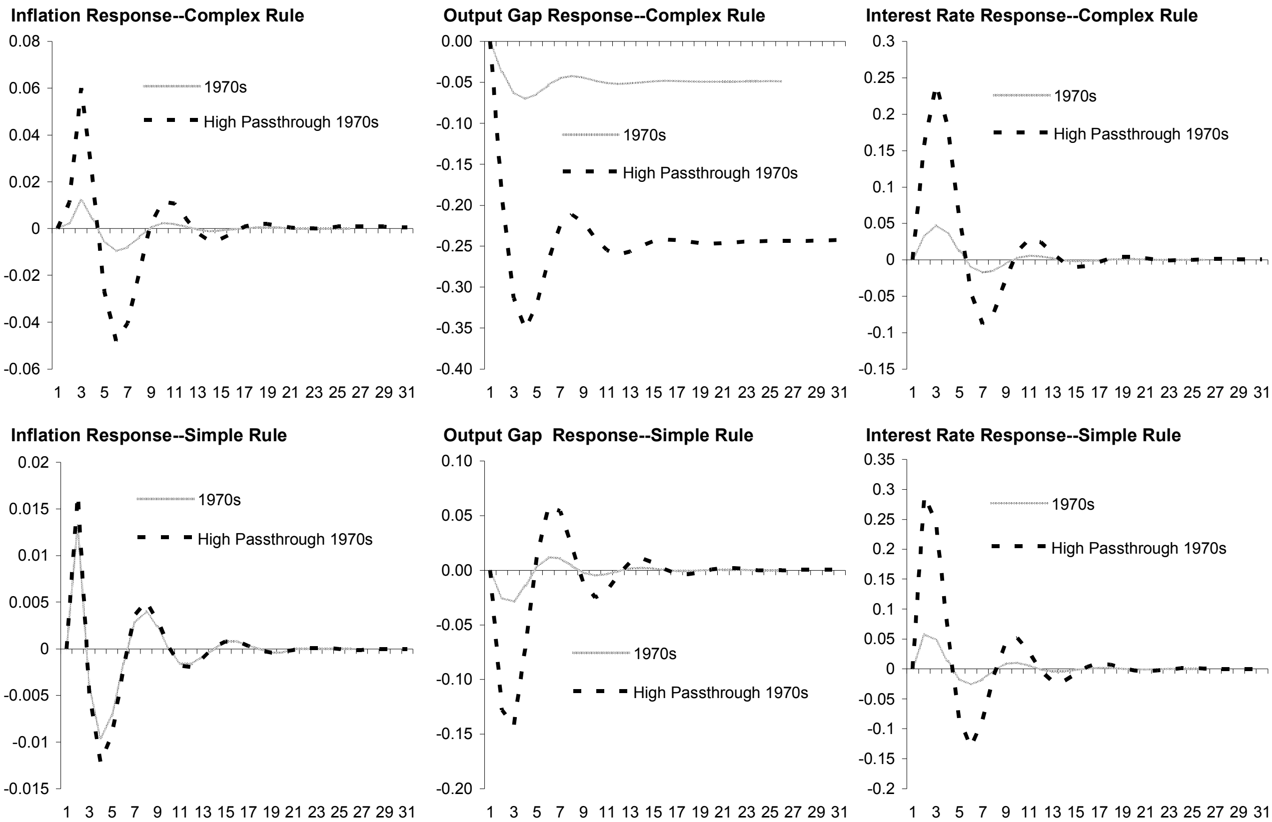
Figure 1. Oil Developments 1970 Q1-2008 Q1



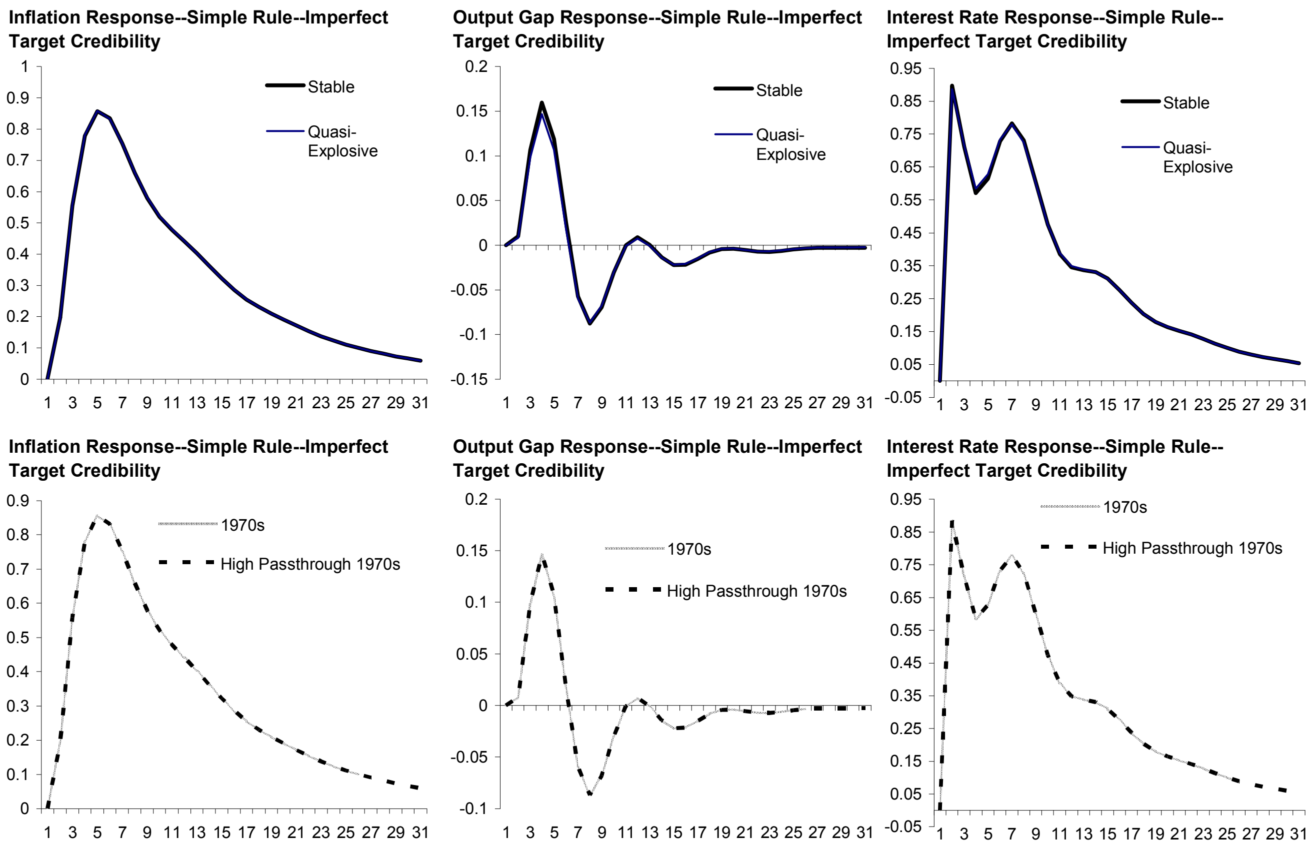
Panel 1: Inflation Response to a Unit Shock to the Real Log-Level Price of Oil Full Target Credibility Case



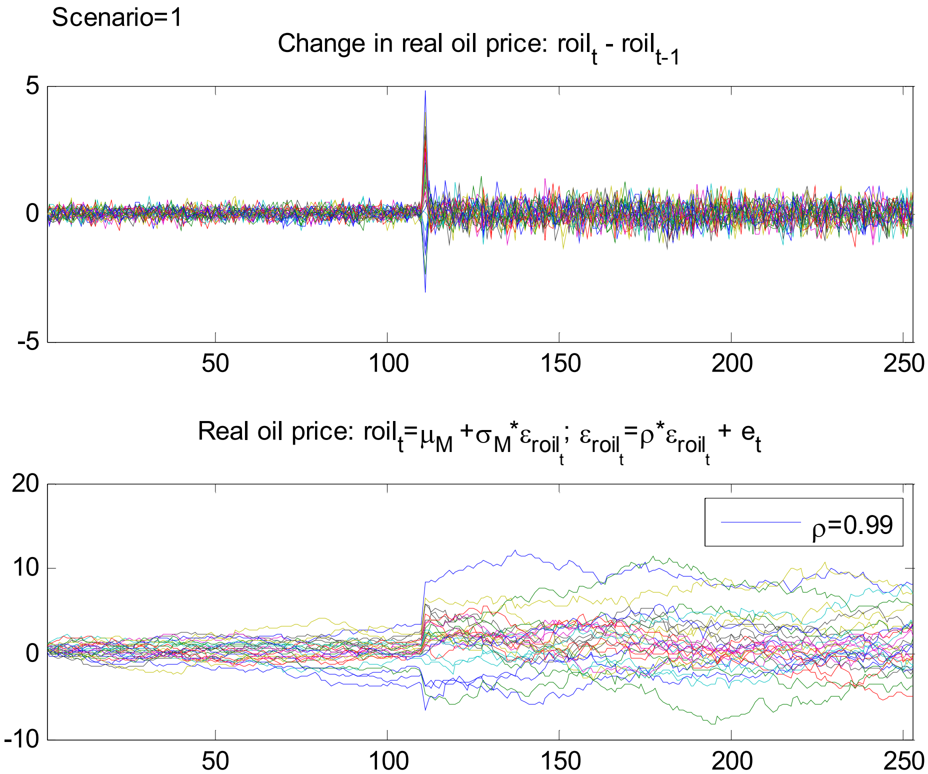
Panel 2: Inflation Response to a Unit Shock to the Real Log-Level Price of Oil (cont.)
Full Target Credibility Case

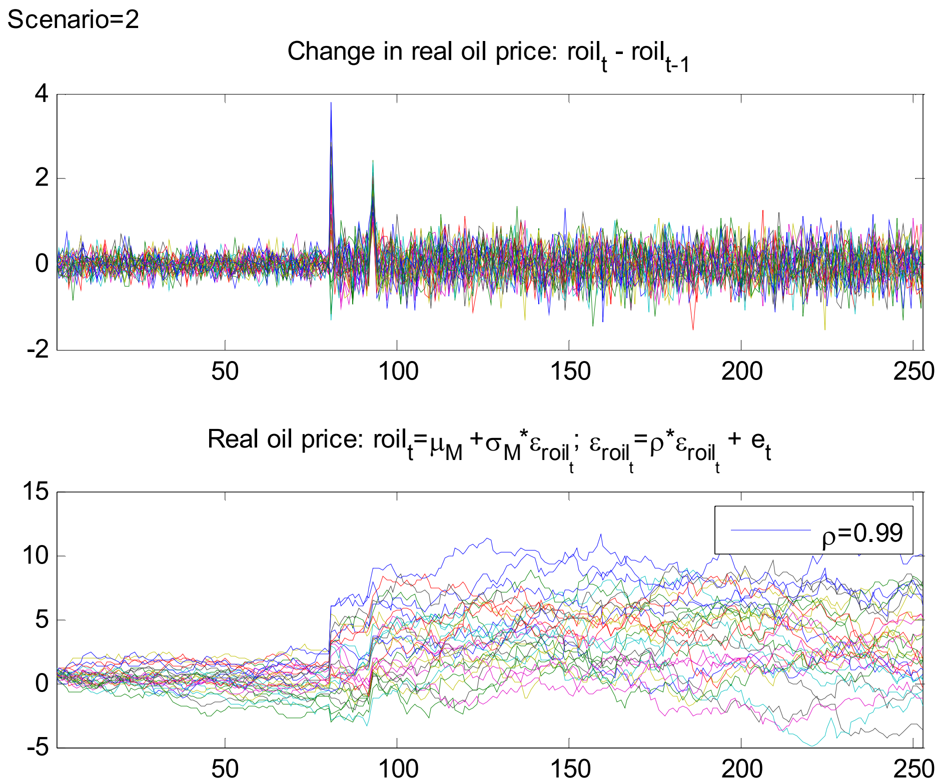


Panel 3: Inflation Response to a Unit Shock to the Real Log-Level Price of Oil (cont.)
Imperfect Target Credibility Case



Panel 4: Alternative Oil Price Scenarios

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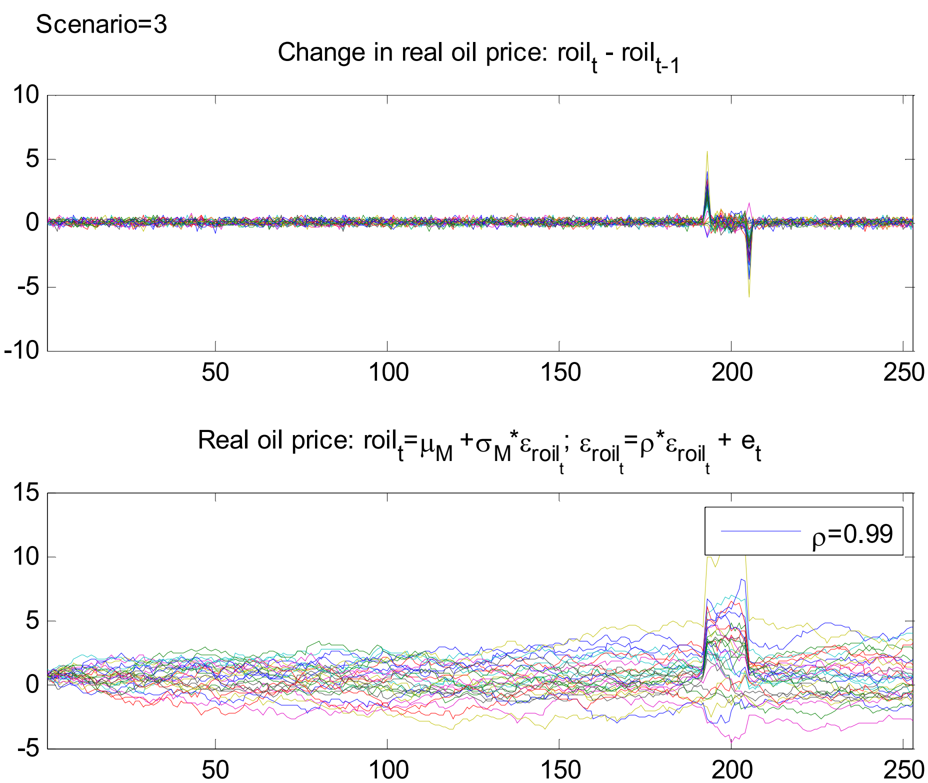
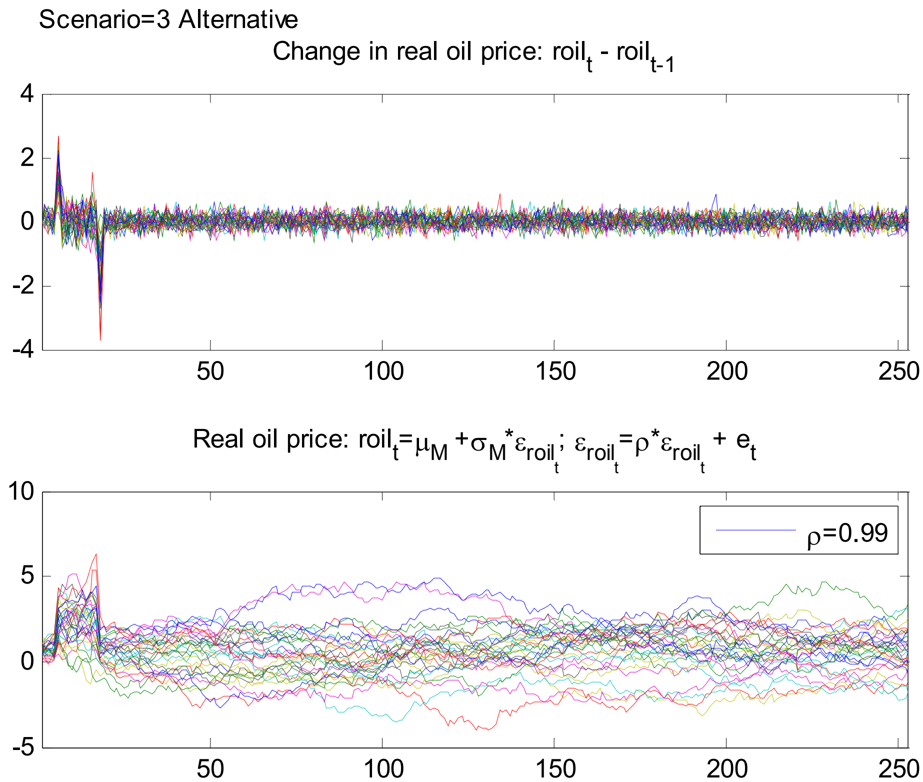
Change in real oil price: roil_t - roil_t-1
Real oil price: roil_t=μ_M +σ_M*ε_roil_t; ε_roil_t=ρ*ε_roil_t + e_t
ρ=0.99


Scenario=3
Change in real oil price: roil_t - roil_t-1
Real oil price: roil_t=μ_M +σ_M*ε_roil_t; ε_roil_t=ρ*ε_roil_t + e_t
ρ=0.99


Scenario=3 Alternative
Change in real oil price: roil_t - roil_t-1
4
2
0
-2
-4
50
100
150
200
250
Real oil price: roil_t=μ_M +σ_M*ε_roil_t; ε_roil_t=ρ*ε_roil_t + e_t
10
5
0
-5
ρ=0.99
50
100
150
200
250