The Macroeconomic Risks of Undesirably Low Inflation*

Jonas Arias[†]
Federal Reserve Board

Christopher Erceg[‡]
Federal Reserve Board

Mathias Trabandt[§]
Federal Reserve Board

September 29, 2015

Abstract

This paper investigates the macroeconomic effects of disinflation using a medium-sized New Keynesian model. We consider different causes of disinflation, including a downward shift in long-run inflation expectations, a fall in nominal wage growth, and a favorable supply-side shock. We show that the macroeconomic effects of disinflation depend crucially on its underlying cause, as well as on the extent to which monetary policy is constrained by the zero lower bound. Various policy options to mitigate these effects are considered.

JEL Classification: E52, E58

Keywords: Disinflation, Inflation Expectations, Wages, Productivity, Monetary Policy, Liquidity Trap, Zero Lower Bound Constraint, DSGE Model.

*Preliminary. Comments welcome. The views expressed in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System or of any other person associated with the Federal Reserve System.

[†]Board of Governors of the Federal Reserve System, Division of International Finance, Global Modeling Studies Section, 20th Street and Constitution Avenue N.W., Washington, D.C. 20551, USA, E-mail: jonas.e.arias@frb.gov.

[‡]Board of Governors of the Federal Reserve System, Division of International Finance, 20th Street and Constitution Avenue N.W., Washington, D.C. 20551, USA, E-mail: christopher.erceg@frb.gov.

[§]Board of Governors of the Federal Reserve System, Division of International Finance, Global Modeling Studies Section, 20th Street and Constitution Avenue N.W., Washington, D.C. 20551, USA, E-mail: mathias.trabandt@gmail.com.

1 Introduction

Given substantial declines in inflation during the past two years, there is heightened concern that inflation may remain undesirably low for a prolonged period in many of the advanced and even emerging market economies.[1] A number of central banks, including the ECB and Bank of Japan, have implemented or stepped up their asset purchase programs to mitigate this risk.

Our paper examines both the macroeconomic causes and consequences of a prolonged period of disinflation. Broadly speaking, we argue that the costs of disinflation depend crucially on its underlying causes, as well as on macroeconomic conditions that may constrain the response of monetary policy. Our analysis differentiates between different sources of low inflation, including i) a fall in long-term inflation expectations, ii) a deceleration in nominal wages in response to persistently weak labor market conditions, iii) a too pessimistic view about potential output, iv) faster TFP growth, and v) persistent slower TFP growth.

We use a medium-scale model similar to that of Christiano, Eichenbaum and Evans (2005) (henceforth CEE) to show that a fall in long-run inflation expectations reduces output substantially when interest rates are expected to remain near zero for a prolonged period, as in the euro area. With interest rates stuck at zero for several years, any downward drift in inflation would be sharply contractionary for output: the liquidity trap duration would be extended, and real interest rates pushed up farther out the yield curve. Moreover, our analysis uses stochastic simulations to highlight how a fall in inflation expectations amplifies downside tail risks; in particular, we show how the probability distribution of output can become sharply skewed to the downside by the

[1]Low inflation may hamper the recovery of an economy by slowing the process of balance sheet repair, and by raising real interest rates given that policy rates are already at zero. ECB officials have emphasized in several speeches that recent measures to provide additional accommodation, including the targeted term lending program and large-scale asset purchases, aim squarely at minimizing the risk of disinflation.

interaction of lower inflation expectations and negative economic shocks.

By contrast, a downward shift in the public's expectations about inflation would have minimal adverse effects on output if the central bank could reduce policy rates in the fairly near-term. Indeed, low inflation could even fuel a stronger recovery to the extent that the central bank had scope to reduce interest rates persistently in real terms. Our results underscore why the ECB and BOJ regard disinflation as a salient downside risk even though other economies with more entrenched recoveries would appear to have less cause for concern, at least if the inflation decline was modest in size.

While the IMF and some other policy institutions have urged greater wage flexibility to boost the competitiveness of periphery economies, our paper shows how a deceleration in nominal wages can also have sharply contractionary effects if monetary policy is constrained from reducing interest rates. In particular, because lower wage growth reduces inflation in the near-term, real interest rates would rise and GDP would contract even in the fortuitous case in which long-run inflation expectations remained anchored. The sharp fall in nominal wage growth in the euro-area periphery during the past couple of years suggests that such a broad-based wage and price deceleration is a material risk.[2]

Our analysis concludes by underscoring that low inflation may not always require corrective policy action. In this vein, we show that favorable and persistent supply shock, perhaps associated with structural reform, is likely to raise output even if the zero lower bound is binding. Moreover,

[2] In a future draft of our paper, we will include a formal analysis that considers the role of monetary policy in mitigating both the risk and possible effects of disinflation. We argue that policy rules that put more weight on resource slack are likely to be effective in combatting deflationary pressure. Moreover, using a more encompassing measure of resource slack that includes e.g., the long-term unemployed or cyclical dropouts from the labor force, is likely to keep inflation closer to target on average, even if increasing the chances of an eventual overshooting of a central bank's inflation target.

our paper attempts to provide practical guidance about how to differentiate between the risks posed by a persistent fall in inflation. If inflation fell due to a productivity growth pickup, nominal wage growth would tend to rise, stock prices increase, and risk spreads narrow – a "good disinflation" scenario. By contrast, alternative "bad disinflation" scenarios such as those discussed above that can lead to sizeable output declines tend to be associated with decelerating wages, falling stock prices, and rising risk spreads.

2 A Medium-Sized New Keynesian Model

Our model is a slightly simplified variant of the CEE model. As such, our model incorporates nominal rigidities by assuming that labor and product markets exhibit monopolistic competition, and that wages and prices are determined by staggered nominal contracts of random duration following Calvo (1983) and Yun (1996). In addition, the model includes an array of real rigidities, including habit persistence in consumption and costs of changing the rate of investment. Monetary policy follows a Taylor rule subject to the zero bound constraint on policy rates.

2.1 Firms

Final Goods Production. We assume that a single final output good Y_t is produced using a continuum of differentiated intermediate goods $Y_t(f)$. The technology for transforming these intermediate goods into the final output good is constant returns to scale, and is of the Dixit-Stiglitz form:

$$Y_t = \left[\int_0^1 Y_t\left(f\right)^{\frac{1}{1+\theta_p}} df \right]^{1+\theta_p} \tag{1}$$

where $\theta_p > 0$.

Firms that produce the final output good are perfectly competitive in both product and factor markets. Thus, final goods producers minimize the cost of producing a given quantity of output Y_t, taking as given the price $P_t(f)$ of each intermediate good $Y_t(f)$. Moreover, final goods producers sell units of the final output good at a price P_t that can be interpreted as the aggregate price index:

$$P_t = \left[\int_0^1 P_t(f)^{-\frac{1}{\theta_p}} df\right]^{-\theta_p}. \tag{2}$$

Intermediate Goods Production. A continuum of intermediate goods $Y_t(f)$ for $f \in [0,1]$ is produced by monopolistically competitive firms, each of which produces a single differentiated good. Each intermediate goods producer faces a demand function for its output good that varies inversely with its output price $P_t(f)$, and directly with aggregate demand Y_t :

$$Y_t(f) = \left[\frac{P_t}{P_t(f)}\right]^{\frac{1+\theta_p}{\theta_p}} Y_t. \tag{3}$$

Each intermediate goods producer utilizes capital services $K_t(f)$ and a labor index $L_t(f)$ to produce its respective output good. The form of the production function is Cobb-Douglas:

$$Y_t(f) = K_t(f)^{\alpha} \left(z_t L_t(f)\right)^{1-\alpha} - z_t \phi \tag{4}$$

where ϕ represents a fixed cost of production. Firms face perfectly competitive factor markets for hiring capital and the labor index. Thus, each firm chooses $K_t(f)$ and $L_t(f)$, taking as given the level of unit-root neutral technology z_t, as well as the rental price of capital R_{Kt} and the aggregate wage index W_t. Firms can costlessly adjust either factor of production. Thus, the standard static first-order conditions for cost minimization imply that all firms have identical marginal cost per unit of output.

The prices of the intermediate goods are determined by Calvo-Yun style staggered nominal contracts. In each period, each firm f faces a constant probability, $1-\xi_p$, of being able to reoptimize its price $P_t(f)$. The probability that any firm receives a signal to reset its price is assumed to be independent of the time that it last reset its price. If a firm is not allowed to optimize its price in a given period, we assume that it adjusts its price by a weighted combination of the lagged and steady state rate of inflation, i.e., $P_t(f) = \pi_{t-1}^{\iota_p}\pi^{1-\iota_p}P_{t-1}(f)$ where $0 \leq \iota_p \leq 1$. A positive value of ι_p introduces structural inertia into the inflation process.[3]

2.2 Households

We assume a continuum of monopolistically competitive households (indexed on the unit interval), each of which supplies a differentiated labor service to the production sector; that is, goods-producing firms regard each household's labor services $N_t(h)$, $h \in [0,1]$, as an imperfect substitute for the labor services of other households. It is convenient to assume that a representative labor aggregator combines households' labor hours in the same proportions as firms would choose. Thus, the aggregator's demand for each household's labor is equal to the sum of firms' demands. The labor index L_t has the Dixit-Stiglitz form:

$$L_t = \left[\int_0^1 N_t(h)^{\frac{1}{1+\theta_w}}\, dh\right]^{1+\theta_w} \tag{5}$$

where $\theta_w > 0$. The aggregator minimizes the cost of producing a given amount of the aggregate labor index, taking each household's wage rate $W_t(h)$ as given, and then sells units of the labor index to the production sector at their unit cost W_t:

$$W_t = \left[\int_0^1 W_t(h)^{-\frac{1}{\theta_w}}\, dh\right]^{-\theta_w} \tag{6}$$

It is natural to interpret W_t as the aggregate wage index. The aggregator's demand for the labor hours of household h – or equivalently, the total demand for this household's labor by all goods-producing firms – is given by

$$N_t(h) = \left[\frac{W_t}{W_t(h)}\right]^{\frac{1+\theta_w}{\theta_w}} L_t \tag{7}$$

The utility functional of a typical member of household h is

[3] In a future version of our paper we will examine the implications for our disinflation scenarios when firms are not allowed to index their prices.

$$\mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \{\nu_{t+j} \ln\{C_{t+j}(h) - bC_{t+j-1}\} - \frac{\chi_0}{1+\chi} N_{t+j}(h)^{1+\chi}\} \tag{8}$$

where the discount factor β satisfies $0 < \beta < 1$. The period utility function depends on household h's current consumption $C_t(h)$, as well as lagged aggregate per capita consumption to allow for the possibility of external habit persistence as in Smets and Wouters (2007). A positive consumption preference shock ν_t raises the marginal utility of consumption associated with any given consumption level. The period utility function also depends inversely on hours worked $N_t(h)$.

Household h's budget constraint in period t states that its expenditure on goods and net purchases of financial assets must equal its disposable income:

$$\begin{aligned} & P_t C_t(h) + P_t I_t(h) + \int_s \xi_{t,t+1} B_{D,t+1}(h) - B_{D,t}(h) \\ = \; & W_t(h) N_t(h) + R_{K,t} K_{t-1}(h) + \Gamma_t(h) - T_t(h) \end{aligned} \tag{9}$$

Thus, the household purchases the final output good, which it chooses either to consume $C_t(h)$ or invest $I_t(h)$. The production of investment goods uses a linear technology in which one unit of the final output good is transformed into Ψ_t units of $I_t(h)$. Investment in physical capital augments the household's (end-of-period) capital stock $K_t(h)$ according to:

$$K_t(h) = (1-\delta)K_{t-1}(h) + [1 - S(I_t(h)/I_{t-1})]\, I_t(h), \tag{10}$$

where $S(\cdot)$ is a convex cost of adjusting investment. The functional form of $S(\cdot)$ is discussed below.

In addition to accumulating physical capital, through the net acquisition of state-contingent bonds. We assume that agents can engage in frictionless trading of a complete set of contingent claims. The term $\int_s \xi_{t,t+1} B_{D,t+1}(h) - B_{D,t}(h)$ represents net purchases of state-contingent domestic bonds, with $\xi_{t,t+1}$ denoting the state price, and $B_{D,t+1}(h)$ the quantity of such claims purchased at time t. Each member of household h earns labor income $W_t(h) N_t(h)$ and capital rental income of $R_{K,t}K_{t-1}(h)$. Each member also receives an aliquot share $\Gamma_t(h)$ of the profits of all firms, and pays a lump-sum tax of $T_t(h)$ (this may be regarded as taxes net of any transfers).

In every period t, each member of household h maximizes the utility functional (8) with respect to its consumption, investment, (end-of-period) capital stock, bond holdings, and holdings of contingent claims, subject to its labor demand function (7), budget constraint (9), and transition equation for capital (10). As in Erceg, Henderson and Levin (2000), households also set nominal wages in Calvo-style staggered contracts that are generally similar to the price contracts described above. Thus, the probability that a household receives a signal to reoptimize its wage contract in a given period is denoted by $1-\xi_w$. In addition, we specify a dynamic indexation scheme for the adjustment of the wages of those households that do not get a signal to reoptimize, i.e., $W_t(h) = \pi_{t-1}^{\iota_w}\pi^{1-\iota_w}\mu W_{t-1}(h)$, where μ denotes the unconditional growth rate of output. Dynamic indexation of this form introduces some structural persistence into the wage-setting process.[4]

2.3 Monetary Policy, Resource Constraint and Functional Forms

We now define our version of the Taylor rule that takes the non-negativity constraint on the nominal interest rate into account. Let Z_t denote a gross 'shadow' nominal rate of interest, which satisfies the following Taylor-style monetary policy rule:

$$\ln(Z_t/Z) = \gamma_z \ln(Z_{t-1}/Z) + (1-\gamma_z)\left[\gamma_\pi \ln(\pi_t/\pi_t^*) + \gamma_x \ln\left(L_t/L_t^f\right)\right], \tag{11}$$

where π_t^* is the central bank's inflation target, which is assumed to follow an AR(1) process. Also L_t^f denotes the *potential* level of hours worked (or employment), meaning the level of hours that would prevail in the absence of any price or wage rigidities; thus, monetary policy can be regarded

[4] In a future version of our paper we will examine the implications for our disinflation scenarios when firms are not allowed to index wages. Likewise, we are planning to explore the consequences of using a search and matching labor market model along the lines of Christiano, Eichenbaum and Trabandt (2013) for our disinflation scenarios.

as responding to the employment gap. The actual (gross nominal) policy rate, R_t, is determined as follows:

$$\ln R_t = \max\{0, \ln Z_t\}. \tag{12}$$

Finally, total output (or GDP) is subject to the resource constraint:

$$Y_t = C_t + I_t/\Psi_t + z_t G$$

where G denotes government consumption.

Further, market clearing in capital and labor markets requires:

$$\begin{aligned} L_t &= \int N_t(h)dh = \int N_t(f)df \\ K_t &= \int K_{t-1}(h)dh = \int K_t(f)df. \end{aligned}$$

Perfect competition in the production of investment goods implies that the nominal price of investment goods equals the corresponding marginal cost:

$$P_{I,t} = P_t/\Psi_t.$$

We assume that $\ln \mu_{z,t} \equiv \ln(z_t/z_{t-1})$ and $\ln \mu_{\Psi,t} \equiv \ln(\Psi_t/\Psi_{t-1})$ follow a first order autoregressive process.

The sources of growth in our model are neutral and investment-specific technological progress. Let:

$$\Phi_t = \Psi_t^{\frac{\alpha}{1-\alpha}} z_t. \tag{13}$$

Given the specification of the exogenous processes in the model, $Y_t/\Phi_t, C_t/\Phi_t$, and $I_t/(\Psi_t\Phi_t)$ converge to constants in nonstochastic steady state.

We assume that the cost of adjusting investment takes the form:

$$S(I_t(h)/I_{t-1}) = \frac{1}{2}\left(\exp\left[\sqrt{\psi_I}\left(I_t(h)/I_{t-1} - \mu \times \mu_\Psi\right)\right] + \exp\left[-\sqrt{\psi_I}\left(I_t(h)/I_{t-1} - \mu \times \mu_\Psi\right)\right]\right) - 1.$$

Note that we assume that households take aggregate investment I_{t-1} as given when choosing $I_t(h)$. Also, μ and μ_Ψ denote the unconditional growth rates of Φ_t and Ψ_t. The value of $I_t(h)/I_{t-1}$ in nonstochastic steady state is $(\mu \times \mu_\Psi)$. In addition, the parameter ψ_I denotes the second derivative of $S(\cdot)$, evaluated at steady state.

We assume the following AR(1) process for the consumption preference shifter ν_t

$$\ln \nu_t = (1-\rho_\nu)\ln \nu + \rho_\nu \ln \nu_{t-1} + \sigma_\nu \gamma_{\nu,t}$$

Following Christiano, Eichenbaum and Trabandt (2015), we will make use of a shock to the return on capital which is also assumed to follow an AR(1) process:

$$\ln \Delta_t = (1-\rho_\Delta)\ln \Delta + \rho_\Delta \ln \Delta_{t-1} + \sigma_\Delta \varepsilon_t^\Delta.$$

The stochastic process for the inflation target is given by

$$\ln \pi_t^* = (1-\rho_\pi)\ln \pi^* + \rho_\pi \ln \pi_{t-1}^* + \sigma_\pi \varepsilon_t^\pi + \sigma_{H\pi} e_{t-H}^\pi$$

We assume that $\varepsilon_t^\pi, \varepsilon_t^\nu, \varepsilon_t^\Delta$ and e_t^π are mean zero, unit variance iid shocks. While the ε_t^π allows for contemporaneous shocks to the inflation target, the term e_{t-H}^π is included to allow for the possibility of anticipated shocks to the inflation target that materialize with a delay of H periods.

2.4 Calibration

We set the central bank's inflation target π^* equal to 0.005, consistent with an annualized inflation rate of 2 percent. We set μ and μ_Ψ such that – along a balanced growth path – GDP and investment grow at an annual rate of 1.5 and 2.5 percent, respectively. The discount factor β is set to imply an annualized real interest rate of 1.5 percent. The inflation target, discount factor and balanced growth imply that the annualized quarterly nominal interest rate is 3.5 percent in steady state. The parameter determining the degree of habit persistence in consumption b is set at 0.7 which is similar to the empirical estimate of e.g. Smets and Wouters (2007). The Frisch elasticity of labor supply $1/\chi$ of 0.5 is well within the range of most estimates from the empirical labor supply literature, see e.g. Domeij and Floden (2006).

The capital share parameter α is set to 0.36. The quarterly depreciation rate of the capital stock is set equal to $\delta = 0.025$, implying an annual depreciation rate of 10 percent. We set the cost of adjusting investment parameter $\psi_I = 6$.

We assume a relatively flat Phillips curve by setting the price contract duration parameter ξ_p equal to 0.95. Further, we set ι_p equal to 0.7 and assume a price markup θ_p equal to 0.2. Given strategic complementarities in wage-setting across households, the wage markup influences the slope of the wage Phillips curve. Our choices of a wage markup θ_W equal to 0.2 and a wage contract duration parameter ξ_w equal to 0.8 $-$ along with ι_w set to 0.7$-$ imply that wage inflation is roughly as responsive to the wage markup as price inflation is to the price markup.

The parameters of the monetary policy rule γ_z, γ_π, and γ_x are set equal to 0.75, 1.5 and 0.25, respectively. The government consumption as a share of GDP is set equal to 20 percent.

2.5 Moment Estimation

While the calibration of our model is consistent with a wide range of estimated New-Keynesian DSGE models, we estimate the parameters characterizing the law of motion of the stationary neutral technology shock and the consumption preference shock in order that stochastic simulations generated with such shocks match key macroeconomic moments. This is important because one of our main results consists in showing that the interaction between a fall in inflation expectations, an adverse baseline, and the ZLB constraint, can generate a skewed distribution of output even when the shocks are symmetrically distributed around the baseline.

Let's us begin by describing the stochastic process of the two estimated shocks in the model.

The stationary neutral technology, ε_t, enters firm's production function

$$Y_t(f) = \varepsilon_t K_t(f)^{\alpha} (z_t L_t(f))^{1-\alpha} - z_t \phi$$

and it evolves according to

$$\ln \varepsilon_t = (1-\rho_\varepsilon)\ln \bar{\varepsilon} + \rho_\varepsilon \ln \varepsilon_{t-1} + \sigma_\varepsilon \gamma_{\varepsilon,t} \text{ with } \gamma_{\varepsilon,t} \; iid \; N(0,1).$$

The consumption preference shock, ν_t, enters household utility function

$$\mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \{\nu_t \ln\{C_{t+j}(h) - bC_{t+j-1}\} - \frac{\chi_0}{1+\chi} N_{t+j}(h)^{1+\chi}\}$$

and it evolves according to the AR(1) process described above.

Thus, the parameters to be estimated are ρ_ε, ρ_ν, σ_ε and σ_ν. We will estimate these parameters by minimizing a criterion function based on the squared difference between 19 moments of the data and the respective model implied moments. The moments on which our criterion function is based are listed below:

$$\sigma(y_t), \sigma(\pi_t), corr(y_t, \pi_t)$$

$$corr(y_t, y_{t-i}) \; i = 1, ..., 4$$

$$corr(\pi_t, \pi_{t-i}) \; i = 1, ..., 4$$

$$corr(y_t, \pi_{t-i}) \; i = 1, ..., 4$$

$$corr(\pi_t, y_{t-i}) \; i = 1, ..., 4$$

where y_t denotes the 4-quarter percent change of real GDP growth per capita, and π_t denotes the 4-quarter percent change of PCE inflation excluding food and energy by π_t. The moments of the data are computed using the sample 1965Q1-2015Q1.[5] The model implied moments are computed assuming that the model is not at the zero lower bound constraint.

	posterior mode	standard deviation
ρ_ε	0.982	0.061
ρ_ν	0.983	0.028
σ_ε	1.235	0.860
σ_ν	5.955	2.889

Table 1: Estimated parameters

	$\sigma(y_t)$	$\sigma(\pi_t)$	$corr(y_t, \pi_t)$	
Data:	2.23	2.12	-0.25	
Model:	2.41	1.89	-0.18	
	$corr(y_t, y_{t-1})$	$corr(y_t, y_{t-2})$	$corr(y_t, y_{t-3})$	$corr(y_t, y_{t-4})$
Data:	0.88	0.68	0.44	0.20
Model:	0.92	0.76	0.55	0.36
	$corr(\pi_t, \pi_{t-1})$	$corr(\pi_t, \pi_{t-2})$	$corr(\pi_t, \pi_{t-3})$	$corr(\pi_t, \pi_{t-4})$
Data:	0.98	0.96	0.92	0.87
Model:	0.99	0.98	0.96	0.94
	$corr(y_t, \pi_{t-1})$	$corr(y_t, \pi_{t-2})$	$corr(y_t, \pi_{t-3})$	$corr(y_t, \pi_{t-4})$
Data:	-0.25	-0.24	-0.21	-0.16
Model:	-0.18	-0.18	-0.17	-0.16
	$corr(\pi_t, y_{t-1})$	$corr(\pi_t, y_{t-2})$	$corr(\pi_t, y_{t-3})$	$corr(\pi_t, y_{t-4})$
Data:	-0.22	-0.19	-0.14	-0.07
Model:	-0.17	-0.16	-0.14	-0.12

Table 2: Moments of the data and model implied moments at estimated mode

Table 1 shows the simulated method of moments estimates, and Table 2 shows the moments of

[5] By including the pre-Volcker period and the Great Recession we are exaggerating the volatility of historical shocks. Hence, we are working on robustness analysis which considers a Great Moderation sample extending from 1983 to 2008.

the data and the model implied moments at estimated mode.

3 Five Disinflation Scenarios

We will next show how the effects of disinflation – arising from several alternative sources – are influenced by the zero lower bound constraint on the nominal interest rate. To do so, we begin by constructing the "severe recession" baseline shown in Figure 1a that captures developments likely to precipitate a protracted period at the ZLB, including a persistently negative output gap and sizeable fall in inflation below its 2 percent target. The contraction is induced by two shocks. First, a persistent negative consumption demand shock ν_t which directly impacts on the first order condition for household consumption:

$$\lambda_t(h) = \frac{\nu_t}{C_t(h) - bC_{t-1}},$$

where $\lambda_t(h)$ dentotes the multiplier on the household budget constraint.

Second, a persistent negative shock, Δ_t, to the return on capital, R^k_{t+1}, which directly affects the first order condition for physical capital:

$$\lambda_t(h) = \Delta_t E_t \lambda_{t+1}(h) R^k_{t+1}/\pi_{t+1}.$$

Note that Δ_t is akin to the *financial wedge* discussed in Christiano, Eichenbaum and Trabandt (2015).

In terms of the timing of shocks, we assume that at time $t = -1$ the endogenous state variables of the economy are at their non-stochastic steady state. At time $t = 0$, agents learn about the two shocks ν_0 and Δ_0 and respond accordingly, though with the expectation that the economy will eventually return to the non-stochastic steady state. As in Christiano, Eichenbaum and Trabandt (2015), we assume certainty equivalence and solve the system of fully non-linear equations for T periods using Dynare.

3.1 Decline in Long-Run Inflation Expectations

Let us begin by considering the macroeconomic consequences of a sizeable downward shift in long-run expected inflation. The ZLB constraint on policy rates would make any such downward drift in long-run expected inflation especially problematic. In normal times, the central bank could counter an incipient fall in long-run inflation expectations by sharply reducing policy rates, i.e., cutting the nominal policy rate enough to reduce real interest rates. The more expansionary policy would tend to boost both output and inflation in the near-term. By contrast, a fall in expected inflation would raise real interest rates while the ZLB was binding, forcing the central bank to rely on forward guidance –and possibly nontraditional tools such as asset purchases – to offset the contractionary effects.

Figure 1a simulates the effects of a decline in long-run expected inflation. In our simulations, long-run inflation declines because the public comes to believe that the central bank will eventually choose to target a somewhat lower level of inflation than π^*. Specifically, we assume that the public suddenly comes to believe that the central bank will reduce its inflation target to 1.5 percent five years in the future. While highly stylized, this characterization is useful for capturing how an "unwanted" fall in long-run inflation expectations might play out: because the central bank's inflation target doesn't actually change in the near-term, the central bank attempts to counter the downward pressure on inflation by easing monetary policy to the extent that it has scope to do so.

Because the economic effects depend critically on the degree to which monetary policy is constrained from reducing policy rates, Figure 1a examines two scenarios.

In the "Outside ZLB" case – shown by the black dash-dotted lines – the shift in inflation expectations occurs after the economy has largely returned to steady state: in particular, the dash-dotted line shows that in quarter 20 agents suddenly come to believe that the inflation target will decline to 1.5 percent in quarter 40. Because the central bank has latitude to reduce interest rates in real terms, output actually expands slightly above the baseline path (though the Taylor rule is not aggressive enough to keep inflation from declining noticeably below 2 percent).

By contrast, the "During ZLB" scenario depicted by the red dashed lines assumes that the same-sized decline in the long-run inflation target occurs in a deep liquidity trap – quarter 4 in the simulation. In this case, the fall in inflation causes real interest rates to rise markedly in the near-term, and the duration of the zero lower bound is extended over a year. All told, the fall in the perceived long-run inflation target of 1/2 percent causes inflation to fall by twice that amount in the near term, and output to decline about 1-1/2 percent.

These simulations of the effects of a shift in long-run inflation expectations alone may significantly understate the economic costs because they abstract from potentially adverse complementarities between a fall in long-run inflation expectations and other adverse shocks that may also reduce demand. In particular, given the asymmetry posed by the zero bound constraint, a fall in inflation expectations may shift the probability distribution of output downward by much more than suggested by the adverse scenario in Figure 1a.

We next consider the implications of a shift in the inflation target in a stochastic environment. We begin with the case in which monetary policy is unconstrained by the ZLB – the "normal times" case shown in the right panel of Figure 1B. The probability distribution of GDP shown in the panel is generated by simulating the model 5000 times around the baseline GDP path (from Figure 1A) using the estimated distribution of shocks derived from our moment-matching exercise, and hence should be interpreted as showing the distribution of output relative to that baseline path. This (conditional) probability distribution is clearly symmetric around the baseline, as would be expected given that the underlying shocks are normally distributed. Moreover, the red dashed lines show that the probability distribution of output remains essentially unchanged – and symmetric around the baseline – in the case in which the perceived long-run inflation target falls to 1.5 percent.

By contrast, the dashed red line in the left panel shows that the probability distribution of output shifts sharply to the left in the case in which the perceived long-run inflation target declines (to 1.5 percent) and the ZLB is binding. The long left tail of the output distribution reflects that adverse shocks may hit in the unfortuitous circumstance in which the economy is in a deep recession and inflation expectations have drifted down. All in all, these stochastic results highlight how a decline in inflation expectations may pose a serious risk for an economy mired in recession, even if it might have fairly minimal adverse implications for an economy close to full employment.

3.2 Fall in Nominal Wage Growth

There are a number of different developments or shocks that could fuel disinflationary pressure even if long-run inflation expectations remained well-anchored. One risk is that nominal wages may decelerate if long periods of high unemployment or unemployment eventually make wages more sensitive to economic slack. This might occur if worker bargaining power gradually erodes in the face of protracted weakness in labor market conditions, and/or if workers become less averse to cuts in nominal wages.

Empirical evidence from Japan's experience with very low inflation in the 1990s seems consistent with these possibilities. As discussed by Kuroda and Yamamoto (2005), the distribution of nominal wage changes appeared highly concentrated to the right of zero through the early years of Japan's low inflation period, presumably reflecting staunch worker resistance to nominal wage cuts; but the proportion of workers experiencing nominal wage cuts rose markedly as the period of near zero inflation and very weak output growth dragged on.

Figure 2a considers wage adjustment in the aftermath of the financial crisis. In the U.S. case – shown in the upper left panel – wage growth has remained stuck at around 2 percent, only slightly above its crisis lows, notwithstanding a massive fall in the unemployment rate. The U.S. experience suggests that wage growth in the euro area, which has been stuck at around 1 percent per year, is also likely to remain quite subdued, at least if private forecasts calling for unemployment to remain high for several years in fact materialize. Moreover, there is some chance that economies struggling with chronically high unemployment could experience a further deceleration in wages, as occurred in periphery economies including Ireland and Spain.

Faster wage adjustment typically has benign effects in normal times when monetary policy can freely adjust policy rates, notably by easing the tension that may arise between achieving the objectives of stabilizing both inflation and the output gap following an aggregate supply shock. However, a faster speed of nominal wage adjustment is likely to have contractionary effects on output in the context of a sufficiently long-lived liquidity trap. In particular, rapid wage-cutting by workers would put downward pressure on inflation, raising the real interest rate. Because faster wage adjustment does not materially affect the economy's longer run potential output, this real interest rate channel is the main determinant of the effects on output. This contrasts with the productivity shock that we will consider below, in which the negative effects of higher interest rates on aggregate demand are more-than-offset by the prospect of higher future permanent income and enhanced longer-term investment prospects.

Figure 2b illustrates the consequences of faster wage adjustment when monetary policy is constrained by the zero lower bound against the same "severe recession" baseline as in Figure 1a. In particular, we consider a scenario in which nominal wages become more sensitive to economic slack due to a sudden and unforeseen shift in the wage Phillips Curve slope parameter. [6] Because the fall in wage growth causes inflation to decline, real interest rates rise due to the zero lower bound constraint, exerting a sizeable contractionary impact on the economy.

[6]Specifically, we assume that in quarter 4 the Calvo wage parameter drops permanently from θ_w to $\theta_w^{'}$ and that all agents in the model are aware of this change.

3.3 Targeting Broad vs. Narrow Measures of Resource Slack

Our specification of the monetary policy rule has assumed that monetary policy responds only to inflation and the employment gap. Noting the the "true" output gap $\ln Y_t - \ln Y_t^f$ may be expressed – ignoring the fixed cost term for expositional convenience – as:

$$\ln Y_t - \ln Y_t^f = (1-\alpha)(\ln L_t - \ln L_t^f) + \alpha(\ln K_t - \ln K_t^f) \tag{14}$$

our assumption about the policy reaction function implies that monetary policy in effect ignores the possibility of responding to the true capital gap $\ln K_t - \ln K_t^f$. By contrast, a policy rule reacting to the true output gap would implictly put a sizeable weight on responding to the capital gap – of $\frac{\alpha}{1-\alpha}$ as large as the weight on the employment gap, which equals 0.56 under our benchmark calibration. Equivalently, the employment gap rule may be regarded as tantamount to responding to the output gap, but which is based on a measure of potential output Y_t^{pot} that treated the current level of the capital stock as the appropriate measure of potential, i.e.

$$\ln Y_t^{pot} = (1-\alpha)\ln L_t^f + \alpha \ln K_t \tag{15}$$

Following a deep recession in which the capital stock declined sharply, such a measure of potential would lie well below Y_t^f, and hence imply a much smaller output gap than using true potential measure Y_t^f.

A recent literature has argued that – following a deep recession – monetary policy may spur a faster rebound in both inflation and output/employment by targeting a broader measure of resource slack. In particular, Erceg and Levin (2014) show that a policy reaction function which reacts to the labor force participation gap as well as to the unemployment gap induces a much more rapid recovery than a reaction function responding only to the unemployment gap, albeit at the cost of some eventual overshooting of the inflation target. Rudebusch and Williams (2015) make a similar point in a model that distinguishes between the short-run and long-run unemployed.

To explore the consequences of reacting to a broader measure of slack in our model, Figure 3 compares the implications of our baseline policy reaction function which responds only to the employment gap – the solid blue lines — with an alternative which responds to true potential output – the dashed red lines; as noted above, the latter differs from the former only insofar as it assumes a reaction to the capital gap that is $\frac{\alpha}{1-\alpha}$ as large as to the employment gap. The latter reaction function is much more stimulative: because the capital stock reacts very slowly, such a policy in effect acts like a promise to keep real interest rates low for much longer than under employment gap targeting. As a consequence, the employment gap overshoots, and inflation rises persistently above the 2 percent target. A policy reaction function that put a larger weight of unity on the capital gap – the dashed-dotted black lines – would imply an even faster recovery, and greater overshooting of inflation.

Although any of these approaches would seem consistent with flexible inflation targeting, a central bank may well be reluctant to adopt a policy framework that could imply considerable inflation overshooting in the medium-run, and may instead prefer to project a monotonic convergence of inflation to target. The influential research by Orphanides (2003) arguing that the Great Inflation was in large part attributable to overestimating slack might seem to push in the direction of measuring slack very conservatively. However, it is arguable that there is a much more tangible risk of undershooting the inflation target in the environment of the past several years, in which major central banks have almost uniformly missed their targets to the downside, and the ZLB has remained a longstanding constraint. To the extent that greater risks are perceived to lie in the direction of undershooting inflation targets – and policymakers feel reasonably confident of their ability to eventually bring inflation down should it overshoot materially – policy reaction function which focus on broader measures of slack may be appealing.

3.4 Faster TFP Growth

Shocks that raise the economy's longer-run level of potential output tend to put downward pressure on inflation. Familiar examples include a supply-induced decline in global oil prices, or a pickup in productivity growth as occurred in the United States in the late 1990s. More recently, Bank of England officials have argued that extremely weak productivity growth since 2007 helped keep inflation well above the U.K's target through much of the recovery from the financial crisis (until the past year).

In our model, expansionary aggregate supply shocks cause inflation to fall mainly because wages adjust sluggishly, consistent with a large empirical literature analysing the wage adjustment process. Thus, faster productivity growth causes current and future marginal costs of production to decline, which induces firms to lower their prices. An expansionary supply shock would boost current output if monetary policy followed a Taylor-style interest rate reaction function that responded to inflation and the output gap, at least provided that monetary policy was unconstrained by the ZLB. A fall in oil prices due to a global supply shock would also raise output, while lowering inflation.

The effects of an expansion in aggregate supply on GDP when monetary policy is constrained by the ZLB are less straightforward. To the extent that the reaction in normal times would be for monetary policy to cut policy interest rates in response to downward inflation pressure - as is typically the case for supply shocks in our model - the ZLB constraint tempers the expansionary effects on output by causing real interest rates to rise more than if monetary policy were unconstrained. An expansion in aggregate supply may cause output to even contract perversely in a liquidity trap that is expected to be sufficiently long-lived, as has been highlighted in an influential literature, e.g., Eggertsson (2010) and Eggertsson and Krugman (2012).

We next consider the effects of an expansion of aggregate supply against the same baseline considered above. The shock consists of a permanent rise of the level of neutral technology, z_t, and is scaled so that the level of GDP rises about 5 percent above baseline. The shock occurs in quarter 4 when the liquidity trap is expected to last several years.

As seen in Figure 4, the level of output rises even in the short-run. Given that the ZLB binds for a prolonged period, the output gap widens because real interest rates rise more in the near-term than would occur if policy rates could be freely adjusted. Even so, the dampening effect on output coming from higher real interest rates is more than offset by the stimulative long-term effects of the productivity shock on aggregate demand. In particular, aggregate demand is buoyed by the expectation of higher permanent income, a higher marginal product of investment, and by rising real wages. Output would rise even more quickly if the productivity shock occurred later in the recovery (not shown), as the "headwinds" from the ZLB constraint would be comparatively smaller.

A positive supply shock could induce output to contract at least in the near-term, if the ZLB were binding for even longer than considered in our scenario (i.e., more than three years). In addition, greater wage and price flexibility than in our benchmark calibration would tend to reduce the near-term output response by causing real interest rates to increase more. In such an environment, output could contract markedly even in a relatively short-lived liquidity trap (e.g., that was expected to last two years or less). However, such calibrations would imply much more extreme variation in inflation than has been observed since the Great Recession.

Overall, our analysis suggests that if inflation fell relative to baseline because productivity growth picked up, the associated recovery would also be more robust. Even if output fell in the very short-term — as might occur if the ZLB were expected to bind for a prolonged period — the trajectory of output would rise above the baseline relatively quickly. In this sense, disinflation pressure associated with supply shocks could be regarded as "good" or benign for the recovery of the real economy.

3.5 Persistent Slower TFP Growth

The previous scenario suggests that a permanent fall in TFP would cause higher inflation and lower output. In this scenario, we highlight that the effects on inflation and output of a permanent fall in productivity hinge on the persistence of the productivity decline. We illustrate this by considering two cases. In the first case, we consider a shock to the growth rate of the unit root neutral technology process coupled with a change in the autocorrelation coefficient of this process − relative to the autocorrelation assumed in the baseline (i.e. 0.2) − which we set to 0 at the time in which the shock is realized. The shock occurs at horizon 4 and it leads to a 5 percent decline in the level of neutral technology upon impact. In the second case, we consider a shock to the growth rate of the unit root neutral technology process coupled with a change in the autocorrelation coefficient of this process − relative to the autocorrelation assumed in the baseline (i.e. 0.2) − which we set to 0.975 at the time in which the shock is realized. The size of the shock is scaled so that it generates a 5 percent decline in the long-run level of neutral technology.

Figure 5a shows the results. The dashed red line shows that a short-lived fall in TFP leads to an increase in the inflation rate and to a decrease in output. In contrast, the black dotted-dashed line shows that a protracted fall in TFP leads to a decrease in the inflation rate and to a decrease in output. In Figure 5b we show that similar results are obtained if the shock occurred outside of the ZLB constraint.

4 Conclusions

We have investigated the macroeconomic effects of disinflation using a medium-sized New Keynesian model. We considered different causes of disinflation, including a downward shift in long-run inflation expectations, a fall in nominal wage growth, and a favorable supply-side shock. We have shown that the macroeconomic effects of disinflation depend crucially on its underlying cause, as well as on the extent to which monetary policy is constrained by the zero lower bound.

5 Figures

Figure 1 a: Effects of a Decline in Long−run Inflation Expectations: ZLB vs. Normal Times

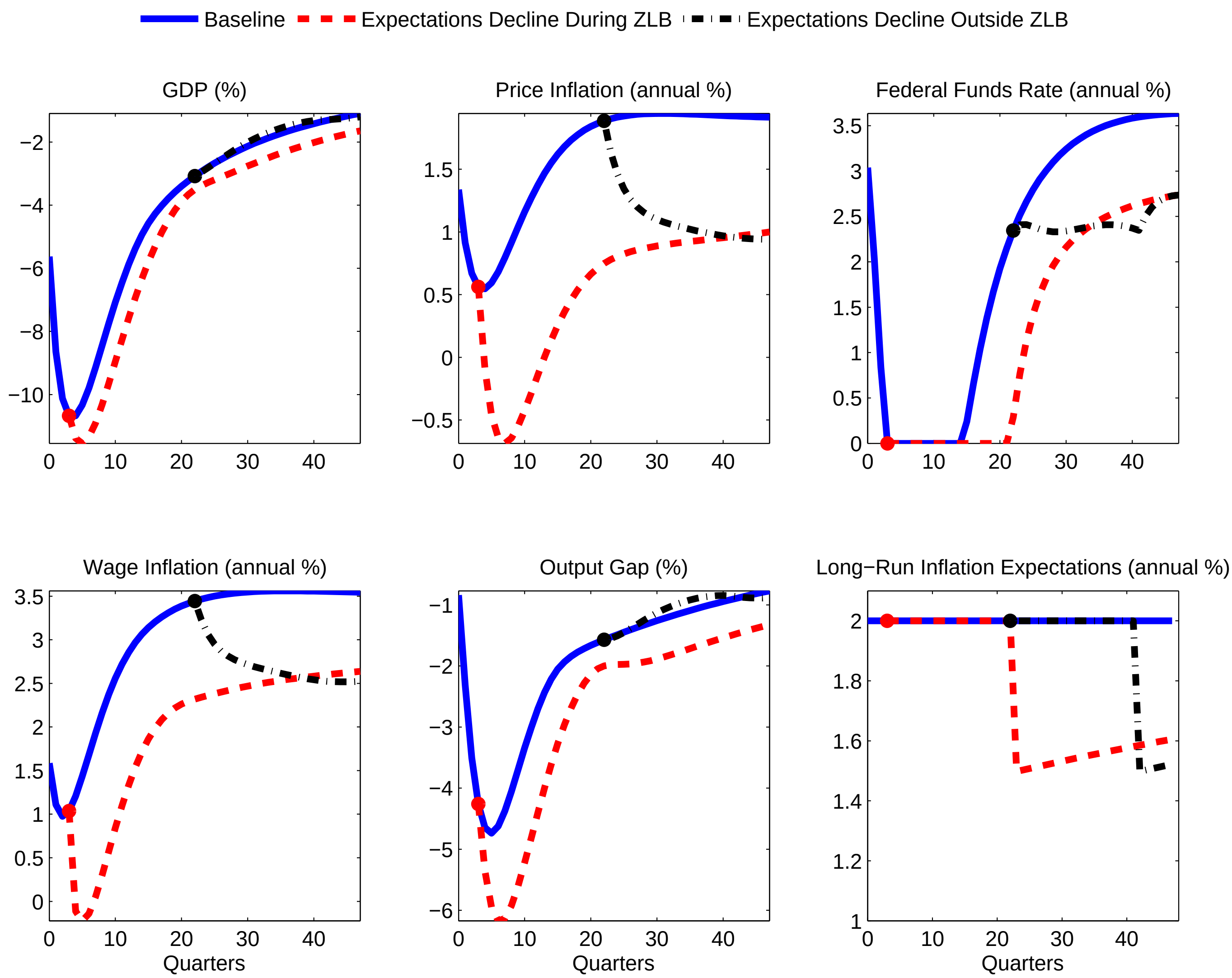


Figure 1 b: Stochastic Simulation of the Effects of Demand and TFP Shocks on GDP

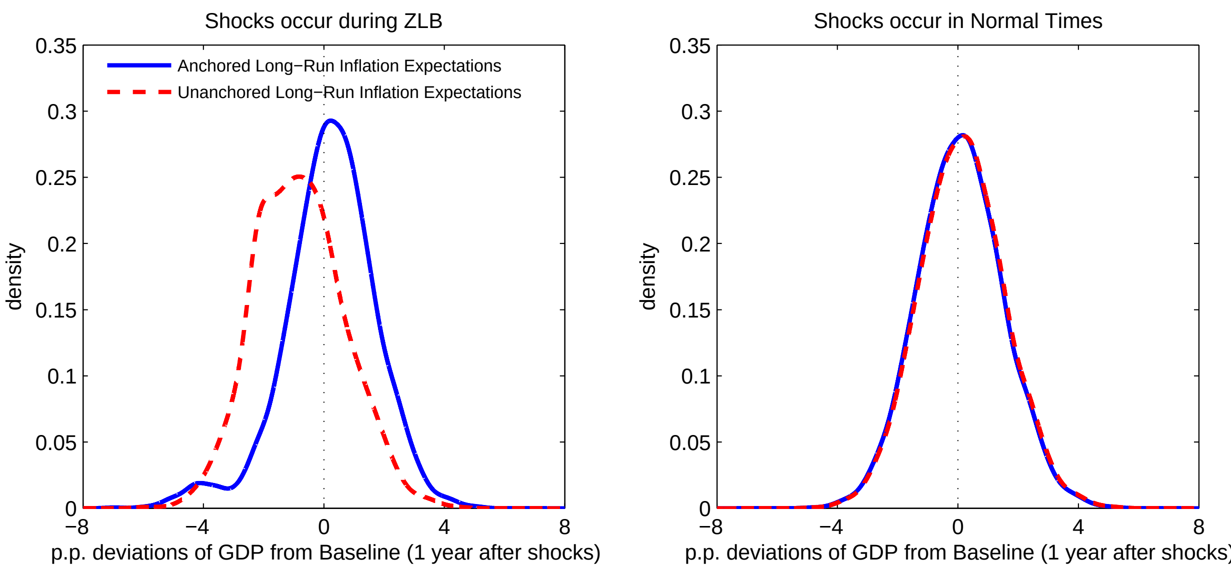


Figure 2 a: Wage Inflation and Unemployment: 2008Q1-2015Q2

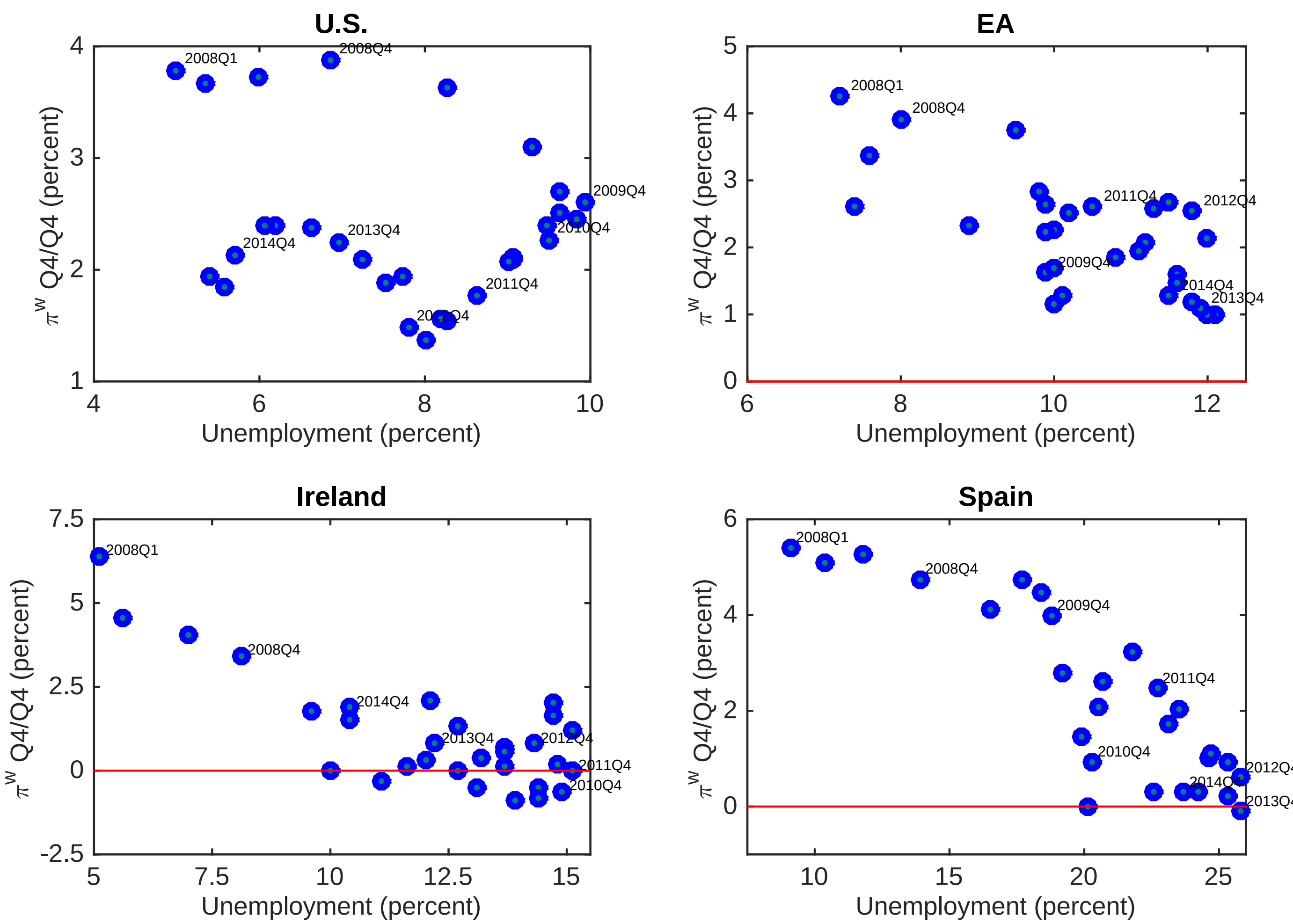


Figure 2 b: Effects of Wages Responding More to Economic Slack

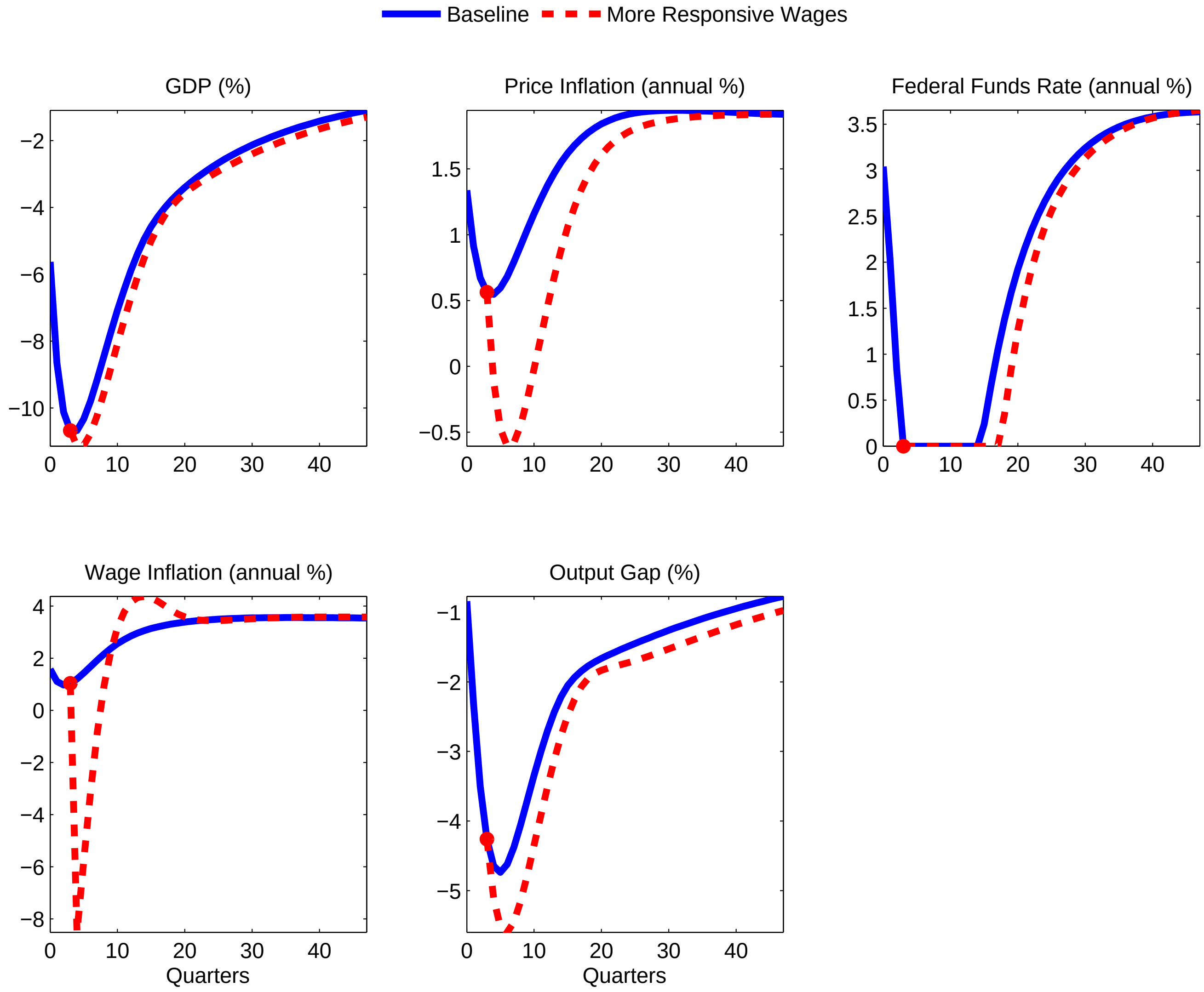


Figure 3 : Effects of Responding to the Capital Gap

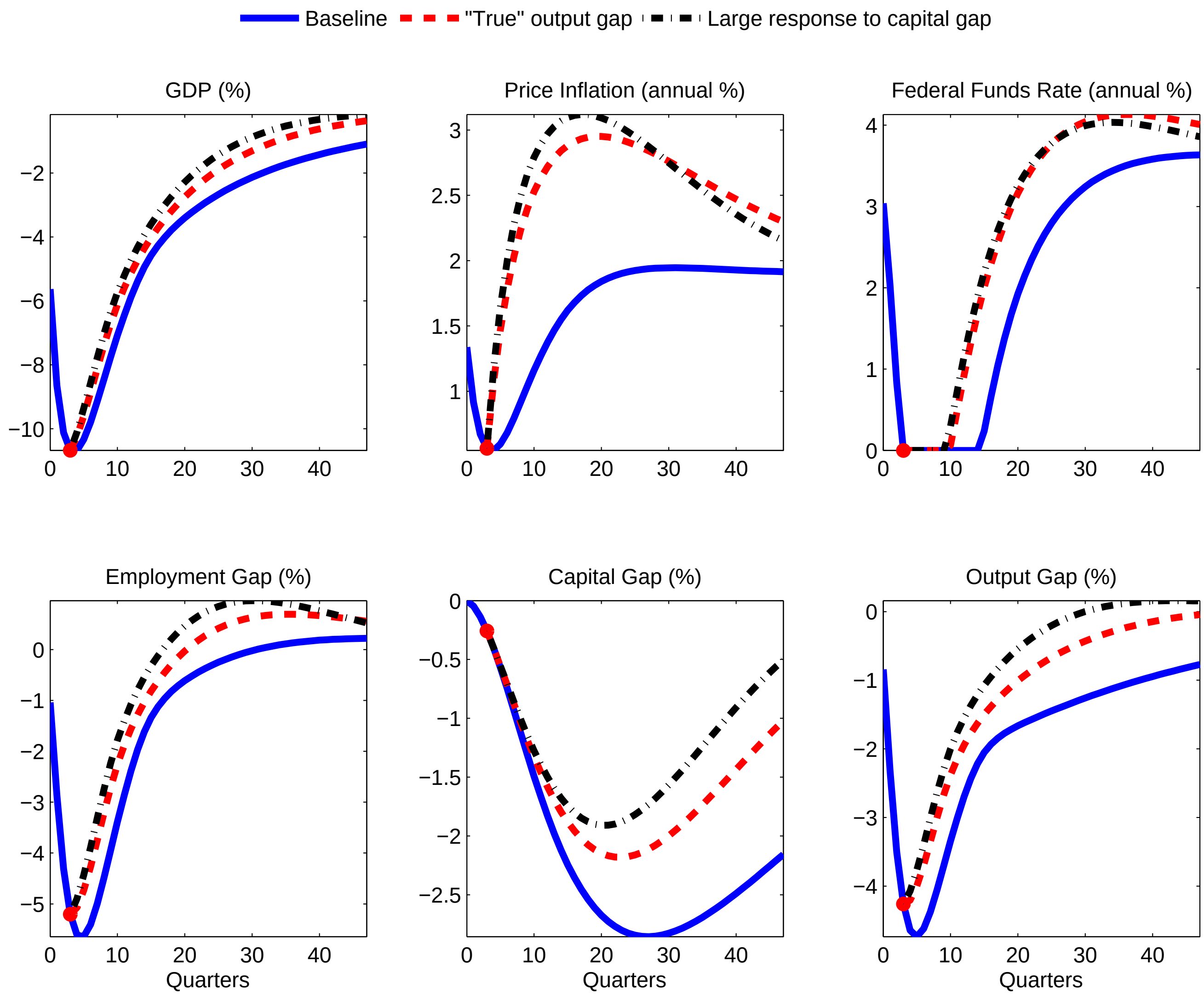


Figure 4: Effects of Faster TFP Growth

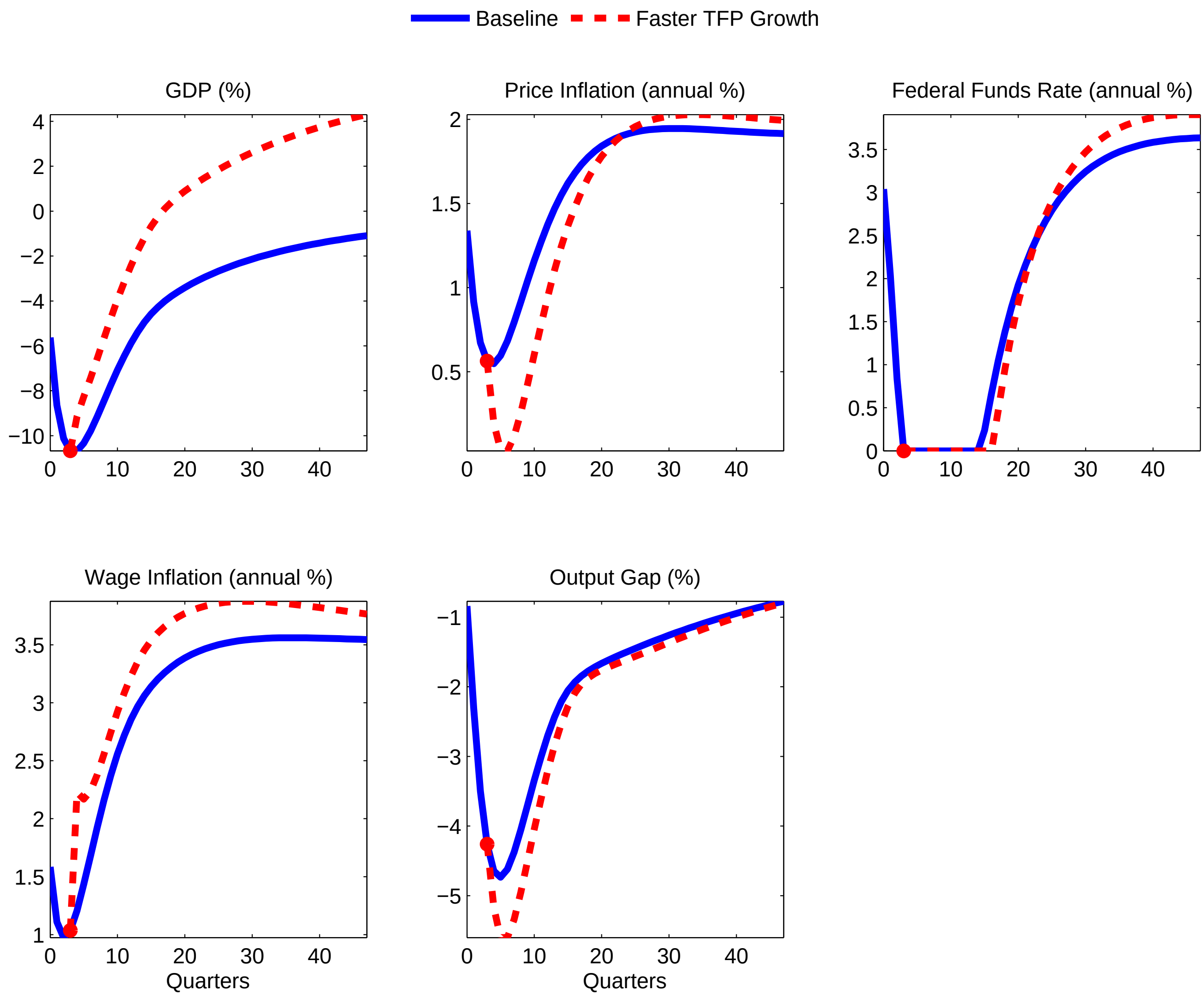


Figure 5 a: Effects of Fall in TFP Growth (At ZLB)

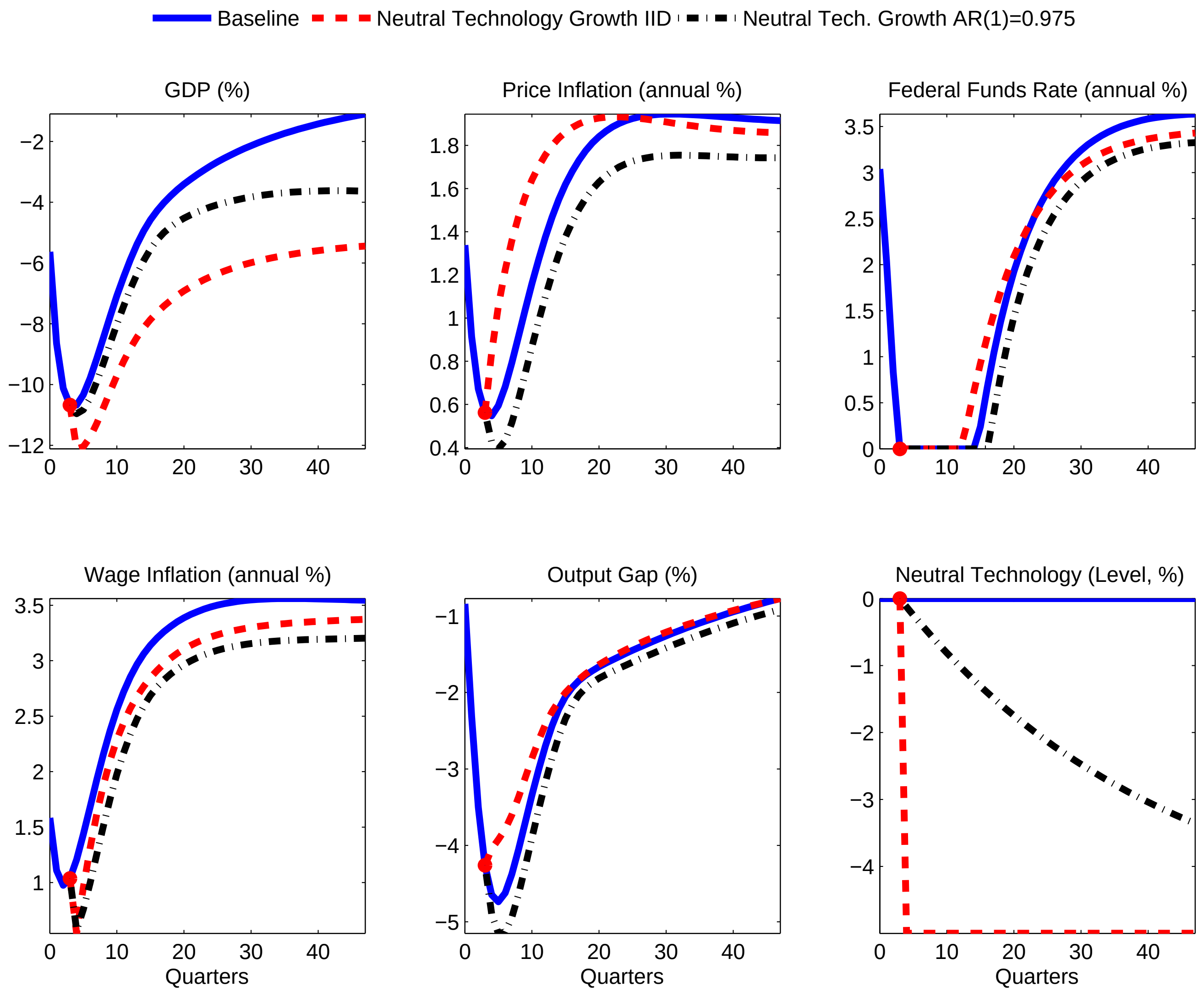
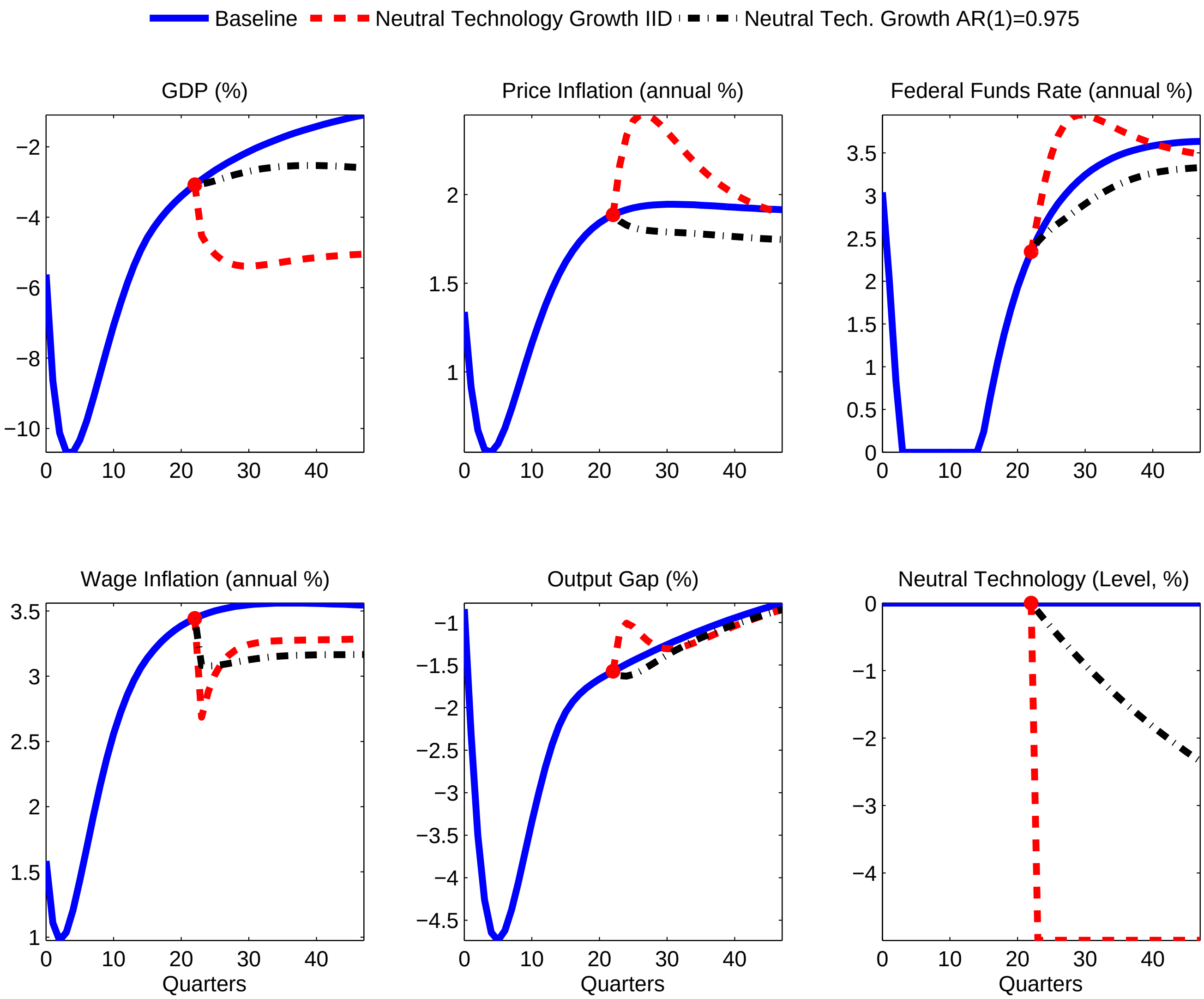


Figure 5 b: Effects of Fall in TFP Growth (Outside ZLB)



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