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MONETARY POLICY STRATEGIES IN THE NEW NORMAL: A MODEL-BASED ANALYSIS FOR THE EURO AREA

by Fabio Busetti*, Stefano Neri*, Alessandro Notarpietro* and Massimiliano Pisani*

Abstract

A New Keynesian model calibrated to the euro area is used to evaluate the stabilization properties of alternative monetary policy strategies when the natural interest rate is low ('new normal') and the probability of reaching the effective lower bound (ELB) is non-negligible. Price level targeting is the most effective strategy in terms of stabilizing inflation and output and of reducing the duration and frequency of ELB episodes. Temporary price level targeting is also effective in mitigating the ELB constraint, although its stabilization properties are inferior to those of price level targeting. Backward-looking average inflation targeting performs well and is preferable to inflation targeting. The effectiveness of these alternative strategies hinges upon the commitment of a central bank to keeping the policy rate 'lower for longer' and is influenced by the agents' expectation formation mechanism.

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1 Introduction[1]

An intense debate among academics and policy-makers is on-going about monetary policy in the "new normal", a macroeconomic environment in which the natural rate may remain lower than its average value over the last five decades in the main advanced economies. The natural rate is the level of the real interest rate that is consistent with the economy growing at its potential rate and inflation being at the central bank's target. Possible factors behind the new normal include a slower rate of technological progress, the demographic transitions associated with population ageing, excess savings in emerging market economies, and an increased demand for safe and liquid assets.[2] The low level of the natural rate implies a low steady-state level of the nominal interest rate and limits the space available to the central bank for reducing the policy rate to stabilize the economy. Periods in which the policy rate is at its effective lower bound (ELB) may be frequent and long-lasting, amplifying the negative effects of recessionary shocks.[3]

Several proposals for conducting monetary policy in the new normal have been put forward in the literature. Some economists have suggested raising the inflation target (Ball 2013, and Blanchard et al. 2010). According to others, central banks should and could rely more extensively on non-standard monetary policy measures, such as forward guidance on the policy rate and the purchases of private and public securities to overcome the limitations posed by the ELB (Bernanke 2017). Another option that has been discussed is to change the monetary policy strategy, involving commitments akin

[1]The views expressed in this paper are those of the authors alone and should not be attributed to the Bank of Italy or the Eurosystem. We thank Pierpaolo Benigno, Francesco Caprioli, an anonymous referee and participants to the Working Group on Econometric Modelling and to the March 2019 Bank of Italy workshop on "Monetary policy in the euro area: non standard measures and the transition towards the New Normal". Any remaining errors are the sole responsibility of the authors. Correspondence: fabio.busetti@bancaditalia.it, stefano.neri@bancaditalia.it, alessandro.notarpietro@bancaditalia.it, massimiliano.pisani@bancaditalia.it.

[2]See Cova et al. (2017), Del Negro et al. (2017), and Neri and Ferrero (2017).

[3]The Federal Reserve recently completed a comprehensive and public review of the monetary policy framework (including strategy, tools and communication) it uses to achieve its mandate of maximum employment and price stability. Similarly, in January 2020 the European Central Bank launched a strategy review, prompted by an economic environment characterized by historically low interest rates and the related limited room for manoeuvre, as well as developments like globalisation, digitalisation, an ongoing ageing population and climate change that are likely to pose new challenges to the economy.

to price level targeting.[4]

This paper contributes to the literature on monetary policy strategies at the ELB by using a medium-scale New Keynesian DSGE model calibrated to the euro area (EA henceforth) to evaluate the stabilization properties of alternative monetary policy strategies when the natural interest rate is low (so called "new normal") and the probability of reaching the ELB is non-negligible. The model, similar to Smets and Wouters (2003), has been extensively used for analyzing monetary policy at central banks and by academic economists. We assume, consistent with the existing empirical evidence, that the natural rate in the EA is low.[5] We use stochastic simulations to feed the model with demand (i.e., risk premium) and supply (i.e., price mark-up) shocks calibrated to generate inflation and output volatilities in line with those of the corresponding EA data over the 1999-2014 period (i.e., before the policy rate hit the ELB).[6] The benchmark monetary policy rule is consistent with flexible inflation targeting (IT, henceforth) and it is in line with the existing literature (see, for example, Warne et al. 2008). The central bank adjusts the policy rate in a systematic way, by responding gradually to deviations of inflation from the target and to output growth.[7]

We compare the IT framework with the following alternative monetary policy strategies: (i) price level targeting (PLT); (ii) temporary PLT (TPLT); (iii) average IT (AIT). We evaluate these strategies along the following dimensions: the probability and duration of an ELB episode; the mean and the volatility of inflation and output; a quadratic loss function.[8] Importantly, in our analysis we abstract from issues related to imperfect credibility of the strategy and/or the overall central bank communication. To the oppo-

[4]See, among others, Bernanke et al. (2019) and Hebden and Lopez-Salido (2018).

[5]See Brand et al. (2018), Busetti and Caivano (2019), and Neri and Gerali (2017).

[6]The choice of the shocks is deliberately parsimonious, reflecting the purpose of capturing the main drivers of business cycle fluctuations. Specifically, on the supply side, mark-up (or cost-push) shocks provide an inefficient source of trade-off between inflation and output stabilization for the central bank, as opposed to technology shocks that are efficient.

[7]The net steady-state growth rate of the economy is set to 0.

[8]As we focus on the euro area, we analyze monetary policy strategies that aim at stabilizing some measure of inflation, in line with the price stability mandate of the European Central Bank. Hence, we do not consider the case of nominal GDP targeting. Although in principle it could allow for inflation stabilization, in terms of communication it may result in a more significant departure from the IT benchmark, compared to the other considered strategies.

site, we implicitly assume that each strategy has been in place for a sufficient amount of time, so that it is fully credible and perfectly understood by all agents in the economy.[9]

Under a PLT strategy, the central bank aims at keeping the price level aligned with a target path. The slope of this path is equal to the steady-state gross inflation rate, which is set to the central bank's target. The key difference between PLT and IT is that, by ignoring past misses of the target, an IT central bank lets "bygones be bygones". To the opposite, a central bank following a PLT strategy commits to reversing temporary deviations of the price level from the target path: a period in which inflation is above its target is expected to be followed by a period in which inflation is below target, and vice versa. Following Bernanke (2017) and Bernanke et al. (2019), we also consider a TPLT strategy according to which the policy rule changes from IT to PLT when the ELB becomes binding. As suggested by Hebden and Lopez-Salido (2018), Bernanke's proposal integrates forward guidance into a policy rate rule, allowing central banks to take into account in their strategy the possibility that ELB episodes may be more frequent and long-lasting. Finally, we modify the benchmark IT rule by allowing the policy rate to react to the average of past inflation rates (AIT).

In the benchmark simulations we assume that households and firms have model-consistent expectations and, thus, fully understand the monetary policy strategy the central bank is following. However, the effectiveness of PLT, AIT, and TPLT in stabilizing inflation strongly depends, in particular, on the degree of forward-lookingness of inflation expectations. For example, following a disinflationary shock, the anticipation of a future temporary inflation target overshooting contributes to stabilize current inflation. If this anticipation effect weakens, the effectiveness of the strategies can decrease. To assess the role of forward-looking inflation expectations, in a robustness analysis we decrease their degree of forward-lookingness by increasing the degree of indexation of current-period inflation to previous-period inflation and, simultaneously, decreasing the indexation to the inflation target. Bernanke et al. (2019) suggested that the assumption

[9] See e.g. Honkapohja and Mitra (2018) for an analysis of the properties of PLT with an evolving degree of credibility over time.

of full credibility of the monetary policy strategy can be too strong during a period of transition to a new regime. If public expectations do not respond as assumed to central bank announcements, then the considered policies could be less effective during ELB periods. For this reason, in addition to the case of fully rational (i.e., model-consistent) expectations, we also consider, as a robustness, the case of "hybrid" inflation expectations, i.e. a weighted-average of two, adaptive and fully rational expectations.

Our results are as follows. First, PLT is the most effective strategy in terms of stabilizing inflation and output and, thus, reducing the duration and frequency of ELB episodes. Second, a TPLT strategy is also effective in terms of likelihood and duration of ELB episodes, although its macroeconomic stabilization properties are inferior to those of PLT. Third, AIT reduces the frequency and duration of ELB episodes as (T)PLT and stabilizes inflation and output less than PLT and TPLT but more than IT. The effectiveness of the strategies hinges upon the commitment of the central bank to keep the policy rate "lower for longer" and it is influenced by agents' expectation formation mechanism.

We contribute to the growing literature on monetary policy strategies to deal with the ELB in the new normal. Bernanke et al. (2019) simulate the FRB/US model to study the effectiveness of lower-for-longer policies when some agents are not forward-looking. The authors find that this feature reduces but does not eliminate the advantages of these policies. Kiley and Roberts (2017) find that, with a policy rule estimated on US data and under the assumption that the steady state nominal policy rate is 3%, monetary policy may be constrained by the ELB as much as one-third of the time. This constraint in turn leads to inferior macroeconomic performance, as the central bank's ability to hit its inflation target or to keep output near potential would be impaired. Schmidt et al. (2016) simulate a DSGE model of the U.S. economy and find that the tail risk induced by the ELB causes inflation to undershoot the target rate and that achieving the latter may be more difficult in the future, if the decline in natural rate has led households and firms to revise up their estimate of the frequency of future ELB events.

Billi and Galí (2018) analyze the impact of the ELB constraint on the welfare effects of greater nominal wage flexibility under alternative monetary policy regimes (Taylor rule vs optimal policy) using the canonical three-equation New Keynesian model and relying on a second-order approximation of the welfare function. Nakata et al. (2020) show, in a stylized New Keynesian model with an occasionally binding borrowing constraint, that a discretionary central bank that stabilizes an average inflation rate, rather than a period-by-period inflation rate, increases welfare. Under rational expectations AIT with a finite, but sufficiently long, averaging window can attain most of the welfare gain from PLT. Under boundedly-rational expectations, if cognitive limitations are sufficiently strong, the optimal averaging window is finite, and the welfare gain of adopting AIT can be small. Amano et al. (2020) simulate a two-agent New Keynesian (TANK) model in which a fraction of firms have adaptive expectations. They examine the optimal degree of history dependence under AIT and find it to be relatively short for business cycle shocks of standard magnitude and duration. In this case, the properties of the economy are quantitatively similar to those under a price-level target.

Our contribution to the literature is twofold. First, compared with the existing studies, which are all based on the US, we study the euro area case. The latter is an interesting case-study because of the very low level of the natural interest rate and the persistently low level of inflation, which has been running below target for a very long time. Second, we use a medium-scale model suitable for policy analysis and non-linear methods to take into account the ELB constraint. Our solution method allows for an endogenous ELB and a quantification of the probability of hitting it in a stochastic environment, but cannot account for the impact of uncertainty or risk on households' and firms' decisions.

The remainder of the paper is organized as follows. Section 2 describes the model, its calibration and the different monetary policy strategies. Section 3 presents and discusses the results of the analysis. Section 4 draws the conclusions.

2 Model

In this Section we provide an overview of the model (Section 2.1), describe the monetary policy instrument rules (Section 2.2), and discuss the calibration (Section 2.3).

2.1 Overview

The model is a standard closed-economy New Keynesian medium-scale DSGE à la Smets and Wouters (2003). The representative household has a standard utility function, separable in consumption (featuring external habit formation) and hours worked. She consumes a non-durable consumption good and invests in two assets: a one-period bond (in zero-net supply) paying the policy rate and physical capital. Investment in physical capital is subject to quadratic adjustment costs. The household supplies labor under monopolistic competition and sets the nominal wage taking as given the labor demand by firms and paying a quadratic adjustment cost à la Rotemberg for adjusting the nominal wage.[10] Nominal wages are indexed, with corresponding weights summing up to one, to previous-period consumer price inflation and to the central bank inflation target. The latter is assumed to be constant in all simulations.

As for the supply side of the economy, there are two sectors, one producing the intermediate good, the other producing the final good. Firms in the intermediate sector combine capital and labor, both supplied by the household, according to a Cobb-Douglas production function. Firms operate under monopolistic competition and set the nominal price of their goods taking the demand as given and paying a quadratic cost as in Rotemberg (1982) when adjusting prices. The prices of goods are indexed to the previous-period inflation rate and to the central bank's target with corresponding weights summing up to one. This feature yields a hybrid New Keynesian Phillips curve, that links current inflation to current marginal costs, future expected inflation, and past inflation.

The intermediate goods are combined by other firms under perfect competition into a

[10] See Rotemberg (1982).

final good used for private consumption, public consumption, and investment purposes.

Public consumption is financed on a period-by-period basis by lump-sum (i.e., non-distortionary) taxes. The public sector budget constraint is always balanced and, thus, there is no public debt. The public consumption good allows us to match the private consumption-to-GDP ratio. We use, as a benchmark, a Taylor-type monetary policy rule, in line with the empirical evidence for the EA. As illustrated in the next section, we modify this rule when simulating the model to assess alternative monetary policy strategies.

Demand and supply shocks feed the model simulations. Specifically, the demand shock is a shock to risk premium, which affects the return of the bond as it adds to the (risk-free) monetary policy rate. This shock enters directly the consumption Euler equation and, via no-arbitrage condition, the optimal choice of physical capital by households.[11] The supply shock is a shock to the price mark-up, that directly affects the New Keynesian Phillips curve. Each shock follows an AR(1) process. We do not consider monetary policy shocks. Thus, the monetary policy rate always follows the assumed instrument rule and does not deviate from the assumed strategy.

2.2 Monetary policy rules

Following the studies that estimate DSGE models for the EA, we assume the following specification for the benchmark monetary policy rule:

$$\frac{R_t}{\overline{R}} = max\left\{\frac{1}{\overline{R}}, \left(\frac{R_{t-1}}{\overline{R}}\right)^{\rho_r}\left(\frac{\pi_t}{\overline{\pi}}\right)^{(1-\rho_r)\rho_\pi}\left(\frac{y_t}{y_{t-1}}\right)^{(1-\rho_r)\rho_y}\right\}. \tag{1}$$

The rule describes how the central bank conducts its monetary policy under a flexible IT strategy. The variable R_t is the gross policy rate and $\overline{R}$ its steady-state value. The parameters $0 \leq \rho_r \leq 1$, $\rho_\pi > 0$, ρ_y measure the sensitivity of the policy rate to its lagged value, to the (quarterly) gross inflation rate (in deviation from the target $\overline{\pi}$), and to the

[11] See Fisher (2015).

quarterly gross growth rate of output y_t/y_{t-1}, respectively.[12] The *max* means that we take into account the (endogenous) ELB (R is the nominal monetary policy rate in gross terms, thus it is equal to 1 at the ELB).

We analyze the properties of alternative rules. Specifically, to model PLT, we modify the previous rule by substituting the price level term for the inflation term:

$$\frac{R_t}{\overline{R}} = max\left\{\frac{1}{\overline{R}}, \left(\frac{R_{t-1}}{\overline{R}}\right)^{\rho_r} \left(\frac{p_t}{\overline{p}}\right)^{(1-\rho_r)\rho_p} \left(\frac{y_t}{y_{t-1}}\right)^{(1-\rho_r)\rho_y}\right\}, \tag{2}$$

where p_t is the period-t nominal price level and $\overline{p}$ the steady-state path of the nominal price level, and $\rho_p > 0$ is a parameter that measures the strength of the response of the policy rate to deviations of the price level from its long-run trend. The slope of the price path is equal to the steady-state gross inflation rate, which is set to the central bank's target. The ratio $p_t/\overline{p}$ measures the "price-level gap" and is defined as the (cumulated) product of current and past inflation rate deviations from the target:

$$\frac{p_t}{\overline{p}} \equiv \prod_{i=0}^{t} \left(\frac{\pi_i}{\overline{\pi}}\right). \tag{3}$$

In the case of an AIT strategy, the policy rate does not react to current inflation, but to the average of current and past inflation rates,

$$\frac{R_t}{\overline{R}} = max\left\{\frac{1}{\overline{R}}, \left(\frac{R_{t-1}}{\overline{R}}\right)^{\rho_r} (\pi_t^{avg})^{(1-\rho_r)\rho_\pi^{avg}} \left(\frac{y_t}{y_{t-1}}\right)^{(1-\rho_r)\rho_y}\right\}, \tag{4}$$

where

$$\pi_t^{avg} \equiv \prod_{i=-k}^{0} \left(\frac{\pi_{t+i}}{\overline{\pi}}\right)^{\frac{1}{k+1}}. \tag{5}$$

is the average of the last $k+1$-quarter inflation rates (comprehensive of the current-quarter inflation rate) and $\rho_\pi^{avg} > 0$ is a parameter that measures the strength of the response of the policy rate to deviations of average inflation from the target.

[12]The lagged interest rate ensures that the policy rate is adjusted smoothly and captures the idea that the central bank prefers to avoid large changes in its policy instrument.

Finally, in line with Bernanke (2017), we consider a TPLT central bank, i.e., we add the cumulative inflation shortfall since the beginning of the ELB spell directly to the IT rule (eq. 1):

$$\frac{R_t}{\overline{R}} = max\left\{\frac{1}{\overline{R}}, \left(\frac{R_{t-1}}{\overline{R}}\right)^{\rho_r} \left(\frac{\pi_t}{\overline{\pi}}\right)^{(1-\rho_r)\rho_\pi} \left(\frac{Z_t}{\overline{p}}\right)^{(1-\rho_r)\rho_{tpl}} \left(\frac{y_t}{y_{t-1}}\right)^{(1-\rho_r)\rho_y}\right\}, \tag{6}$$

where $\rho_{tpl} > 0$ is a parameter that measures the strength of the response of the policy rate to deviations of the price level from its trend, and the inflation shortfall term is

$$Z_t \equiv \prod_{i=t_1}^{t} \left(\frac{\pi_i}{\overline{\pi}}\right)^{\frac{1}{i-t_1+1}}, \tag{7}$$

with t_1 denoting the period in which the economy last entered the ELB under IT, i.e. under rule (1). We follow Hebden and Lopez-Salido (2018) in formulating the TPLT rule. Under TPLT, the central bank reacts to the price level on a temporary basis, when the ELB is binding. On the other hand, the central bank reacts only to inflation deviations from the target (as in the IT case) when the policy rate is away from the ELB.

2.3 Calibration

The model is calibrated at quarterly frequency following Smets and Wouters (2003) and Warne et al. (2008). Both studies employ New Keynesian DSGE models estimated on EA data for the period up to the global financial crisis, using Bayesian methods. The chosen calibration allows our model to adequately capture the dynamics of the main EA variables in "normal times". The only key departure from these contributions is the chosen value for the natural rate. We calibrate the model so that the net natural rate is equal to 0 in steady state, and the steady-state net annualized inflation rate is 2%.[13] The (net) policy rate is 2% as well.[14]

[13] The economy gross growth rate is set to 1.

[14] For evidence of a low level of the natural rate in the EA, see Brand et al. (2018) and Neri and Gerali (2017).

Table 1 reports the (flexible-price) steady-state equilibrium. Private consumption, public consumption, and investment are set to 60%, 20%, and 20% of GDP, respectively.

Table 2 reports the parameters of the monetary policy rules. The response to inflation, ρ_π, is relatively large and equal to 1.9, consistent with the estimated value reported by Warne et al. (2008). The policy rate is adjusted slowly, given that the corresponding coefficient, ρ_r, is set to 0.867. The response to output growth, ρ_y, is set to 0.15. The responses of the policy rate to the price level, ρ_p in Eq. (2), to the cumulative inflation shortfall, $\rho_{tpl} > 0$, in Eq. (6), and to average inflation, ρ_π^{avg} in Eq. (4), are also set to 1.9. The number of past and current inflation rates in the AIT is set to 8. Table 2 also reports parameters regulating preferences and technology. The elasticity of intertemporal substitution is set to 1 (i.e., log preferences in consumption) The consumption habit parameter is set to 0.57. The Frisch labor elasticity is set to 0.667. In the Cobb-Douglas production function, the elasticity of output to physical capital is 0.24 and the elasticity to labor is 0.76. The depreciation rate of physical capital to 0.025. The investment adjustment cost is equal to 3. The elasticities of substitution among good and labor varieties are set to 6 and 4.3, respectively, which correspond to steady-state mark-ups of 1.2 and 1.3. Concerning nominal rigidities, the parameter measuring the cost for adjusting the price of goods is set to 120, which corresponds to an average length of 5 quarters between price adjustments. The one for adjusting nominal wages is set to 300 (corresponding to an average length of 10 quarters between wage adjustments). The parameter that measures the degree of indexation to previous-period inflation is set to 0.40 and 0.64 for prices and wages, respectively.

The chosen calibration allows us to obtain responses of GDP and inflation to main macroeconomic shocks consistent with those estimated by Warne et al. (2008) with a DSGE model of the EA. We simulate a shock to risk premium on bonds (i.e., an aggregate demand shock) and a shock to the price mark-up (aggregate supply). The log of shocks follows an AR(1) process, with persistence and standard deviations calibrated to generate inflation and GDP volatilities in line with those of the corresponding EA data over the 1999-2014 period (i.e., before the EA policy rate hit the ELB).

3 Results

To gain some insights on the functioning of the different monetary policy strategies, we first present and discuss (Section 3.1) impulse responses to risk premium and price mark-up shocks. Both recessionary (adverse) and expansionary (favorable) shocks are simulated, that move the policy rate towards and away from the ELB, respectively.

In Section 3.2 we carry out stochastic simulations to evaluate the alternative strategies, based on the frequency and duration of ELB episodes and a loss function. The model is simulated under certainty equivalence using a Newton-type algorithm. In the impulse response analysis, agents are surprised by the shock in the initial period and anticipate the whole future path of the shock. In the simulation analysis, agents are surprised by a new realization of the shocks in every period.

3.1 Impulse responses

We use impulse responses to study the transmission mechanism of the positive and negative shocks under the alternative monetary policy strategies and assess their performance. Considering both positive and negative realizations of the shocks clarifies the transmission mechanism and helps interpreting the results of the stochastic simulations, where the two types of shocks occur contemporaneously and can randomly assume positive or negative values.

3.1.1 Risk premium shock

Fig. 1 reports the responses to a positive (i.e., recessionary) risk premium shock under the alternative monetary strategies. The size of the shock is calibrated so that the policy rate hits the ELB under IT (eq. 1). As explained in Fisher (2015), the risk premium shock increases the return of the bond, providing households an incentive to save in this asset, rather through capital accumulation. The net result is a tendency for consumption and investment to move in the same direction. Given the lower current and expected future aggregate demand, firms immediately decrease both production and prices. Lower inflation and economic activity induce the central bank to cut the policy rate. Under an IT strategy (black solid lines in Fig. 1), when the ELB is reached in the fifth quarter, the expected real policy rate (not reported) increases, amplifying the negative effects of the risk premium shock on consumption and investment. The policy rate remains at the ELB for five quarters, from quarter five to quarter nine. In the tenth quarter, the central bank raises the policy rate and exits from the ELB.

We then turn to studying the stabilization properties of the alternative strategies by feeding the model with the same shock. The impulse responses for the PLT (Eq. 2), AIT (Eq. 4), and TPLT (Eq. 6) cases are also shown in Fig. 1. Under a PLT strategy (red dashed lines) the policy rate does not reach the ELB. Compared with the IT case, inflation decreases marginally, as consumption and investment do. The intuition is the following. Households anticipate that the central bank will keep the policy rate low for a prolonged amount of time, implementing a "lower for longer" policy. This expectation leads households to reduce consumption by a smaller amount compared to IT. Firms also anticipate a modest decline in the demand for their goods and therefore reduce prices by a smaller amount. The relative improvement in the dynamics of inflation and economic activity induces the central bank to reduce the policy rate by a smaller amount compared with the IT case. In the medium term, inflation temporarily overshoots the central bank's target, allowing the price level to converge to target path.

The results for TPLT (green lines with stars) and AIT (blue lines with cross) are similar to those in the PLT case. Both strategies incorporate the promise to keep the policy rate low for long, which improves households' and firms' expectations about future economic activity and inflation, and leads to better macroeconomic outcomes compared with the IT case. A TPLT strategy also implements a lower-for-longer monetary policy, leading to a smaller decrease in inflation and output compared with IT, and to a larger decrease compared with a PLT strategy. In the case of AIT, agents anticipate that the policy rate will be kept persistently low in response to the low past inflation rates. The average inflation which enters the AIT rule is computed over the last eight quarters, including the current one. This implies that the central bank responds with a lag to the shock and starts raising the policy rate later than in the IT case. The delay in raising the policy rate leads to a relatively smaller decline in inflation and economic activity. Importantly, in neither of the three alternative strategies considered the policy rate reaches its ELB, because of households and firms anticipating a lower-for-longer policy.

Fig. 2 contains the responses to a negative (i.e., expansionary) risk premium shock. Under PLT, households and firms expect the policy rate to increase in a gradual way and to be persistently higher than its baseline value. Agents expect the future lower price level to offset the current and past higher prices. Given the expected path for the policy rate, aggregate demand and inflation increase to a smaller extent compared to IT, in which there is no commitment by the central bank to generate lower inflation in the future to compensate for the current high inflation. By construction, in the case of an expansionary shock a TPLT strategy leads to the same macroeconomic outcomes as an IT strategy, since the policy rate is always away from the ELB. In the AIT case, consumption, investment, and output increase quite significantly, because the central bank raises the policy rate by less, consistent with the lower increase in the average inflation rate.

Summing up, conditionally on risk premium shocks, PLT is the most effective strategy in stabilizing inflation and output. TPLT and AIT also provide more macroeconomic stabilization than IT, the more so in the case of negative realizations of the shock that trigger an ELB episode.

3.1.2 Price mark-up shock

In this section we assess how effective the different monetary policy strategies are in stabilizing output and inflation in the aftermath of a price mark-up shock. The size of the shock is calibrated so that, in the case of a disinflationary mark-up shock, the policy rate reaches and remains at the ELB for three quarters under the IT strategy.[15]

Fig. 3 shows the responses to a negative price mark-up shock. The mark-up shock, which enters the New Keynesian Phillips curve, leads to a fall in inflation and to an expansion in output. Lower consumer prices increase real wages, which leads households to increase hours worked. The increase in labour income raises consumption and investment and, thus, output. The shock creates a short-run stabilization trade-off for the central bank. All the strategies considered are more effective than IT in stabilizing inflation, but less effective with respect to output. Under a PLT strategy, households and firms anticipate that the initial decrease in the price level will be compensated by a future increase. This expectation is supported by a longer period in which the policy rate remains at its ELB compared to an IT strategy. The "lower-for-longer" policy stimulates consumption and investment, leading to a larger increase in output. In the medium-term, inflation temporary overshoots the central bank's target. Overall, PLT stabilizes inflation at the cost a higher volatility of output, reflecting the trade-off generated by the mark-up shock. A TPLT strategy leads to macroeconomic outcomes that are in-between those achieved by means of PLT and IT strategies. Relative to an IT framework, the policy rate reaches the ELB with a two-quarter delay, but leaves it at the same time as IT does. The AIT strategy is also in-between the IT and PLT cases in terms of inflation and output developments. The policy rate does not reach the ELB, as agents anticipate that it will remain lower than in the other strategies, consistently with the slow dynamics of the backward-looking average inflation.

In the case of a positive price mark-up shock (Fig. 4), that raises inflation and lowers output, the impulse responses under IT and TPLT strategies are identical by

[15] See Neri and Notarpietro (2019) for the transmission of a negative cost-push shocks when the ELB interacts with financial frictions.

construction, as the policy rate is away from the ELB for the whole period after the shock. The policy rate increases by more under a PLT strategy than in the other cases, as the price level gap (the difference between the price level and the target path) increases widely and persistently after the shock. Households and firms anticipate the larger increase in the policy rate and, in equilibrium, consumption and investment decrease to a much larger extent, while inflation increases by less. In the AIT case, the responses of inflation and output are similar to those under IT and TPLT strategies. The central bank raises its policy rate very gradually, as the average of inflation responds gradually to the shock.

To sum up, conditionally on price mark-up shocks, PLT is less effective than IT in stabilizing both inflation and output. Instead, a PLT strategy is more effective than an IT one when demand-like shocks hit the economy. TPLT and AIT lead to macroeconomic outcomes that are in-between those that can be achieved under PLT and IT strategies.

3.2 Assessment of the alternative strategies

Following the literature, we define the central bank loss function as:

$$\mathcal{L} = \sigma_\pi^2 + \lambda_y \sigma_y^2, \tag{8}$$

where σ_π^2 and σ_y^2 denote the variance of inflation and output gap, respectively (the output gap is defined as the percent difference between output and its steady-state level). The quadratic functional form is consistent with the notion that central banks view large deviations from the targets as more costly than small variations. We set the weight on output variance, λ_y to 0.5. Bernanke et al. (2019) assign equal weights to inflation and output in the loss function, consistently with the dual mandate of the Federal Reserve System. As we focus on the EA, we assign a relatively larger weight to inflation, in line with the price stability mandate of the European Central Bank. It is common practice to include in the loss also the weighted square change in the policy rate, to penalyze rules that cause the policy rate to hit the ELB. Such term usually has a small weight attached.[16] Given that the ELB is a relevant feature of our analysis and it is explicitly taken into account, we set the weight to zero in the loss function.

To compute the loss function, we run stochastic simulations, because theoretical moments of the model are not available, since the occasionally binding ELB introduces a nonlinearity into the model. It is assumed that in each quarter the economy is hit by realizations of the two (risk premium and mark-up) shocks and that households and firms expect no more shocks in the future. Thus, in each period households and firms are newly surprised by the new realizations of all shocks. The log of shocks follows an AR(1) process, with persistence reported in Table 2. The standard deviations of the two shocks are such that the policy rate is at the ELB approximately 20% of the time under IT and the demand shock explains around 80% of quarterly output growth and quarterly inflation, according to the asymptotic forecast error variance decomposition (i.e., under the assumption that asymptotically the economy is not trapped in the ELB equilibrium). The shocks are such that the model broadly matches the volatilities of the EA GDP growth and inflation over the sample ranging from 1985 to 2014. We report statistics based on 1000 stochastic simulations. Each simulation is 200-quarter long. The first 100 quarters are discarded as burn-in sample. We feed the model with the same realizations of the shocks under the alternative monetary policy strategies.[17][18] Thus, every period, different rules will prescribe different expected paths of the policy rate. The duration of the ELB is not (ex-ante) known but changing period-by-period and across the different monetary policy strategies.

For each rule, Table 3 reports the following statistics: (i) the mean probability of

[16] See e.g. Adalid et al. (2005).

[17] We solve the model using a Netwton-type algorithm. Due to the presence of the ELB, for particularly large realizations of the two shocks the solution method may not reach convergence. In such cases, we apply a homotopy algorithm that reduces the size of the shocks realizations until a solution is obtained. In the reported statistics we only consider the cases in which a solution is effectively obtained. Hence, it may be argued that our solution algorithm underestimates the ELB duration and frequency to some extent.

[18] In the case of TPLT, period t_1 (eq. 7) is computed considering the simulation under the benchmark (IT). Specifically, in each period we check whether, under IT, the policy rate is at the ELB or not, and correspondingly activate the TPLT when necessary. Hence, the TPLT rule coincides with the IT rule by construction whenever the short-term rate is away from the ELB.

hitting the ELB; (ii) the mean duration, in quarters, of ELB episodes; (iii) the mean inflation rate (level, annualized percentage points); (iv) the mean output (% deviation from steady-state level); (v) the standard deviation of inflation from its target; (vi) the standard deviation of output; (vii) the mean monetary policy rate (level, annualized percentage points); (viii) the standard deviation of monetary policy rate; (ix) the loss function.

The main takeaways are the following. An IT strategy delivers, on average, inflation well below the target and output below its steady state. The duration and the frequency of ELB episodes are equal to 4.6 quarters and 20.2%, respectively. The standard deviations of inflation and output are 3.8 and 5.1, respectively. Under PLT, the central bank promises to keep the policy rate lower for longer when price dynamics are subdued. The credible promise has, on average across simulations, a stimulating effect on aggregate demand and, thus, on inflation. In the resulting equilibrium, the duration of ELB is 4 quarters, its frequency about 16%, and inflation is on target and output close to its steady-state value. Moreover, the PLT central bank is very effective in stabilizing both inflation and output. The volatility of inflation is equal to 0.7, the volatility of output to 3.2. TPLT is slightly less effective than PLT in limiting the frequency and duration of ELB episodes. TPLT is also less effective in stabilizing inflation and output than PLT. In the former case, inflation and output volatilities are equal to 2.5 and 3.9, respectively. However, these values are much lower than the corresponding ones under IT. Under an AIT strategy, the frequency and duration of ELB episodes are similar to those of PLT, while average inflation is lower and the volatilities of inflation and output are higher. When compared in terms of the central bank loss function, PLT ranks first, followed, in order, by TPLT, AIT, and, lastly, IT. In all cases, the policy rate is kept at a low level for a prolonged amount of time.

Overall, our results suggest that in a low natural interest rate environment, where disinflationary shocks tend to have large macroeconomic effects because of the ELB, under all the considered regimes the central bank has to promise to keep the policy rate low for a prolonged amount of time. Moreover, PLT is the most effective regime in stabilizing inflation, because it allows for temporary overshooting of the inflation target to stabilize the price level. Finally, the performance of AIT and TPLT is in-between those of IT and PLT, confirming the insights from the impulse response analysis.

3.3 Larger role of price mark-up shocks

In order to assess how the economic environment shapes our main results, we alter the relative importance of demand and supply shocks in the economy and re-run the simulations, to compare the relative performances of alternative monetary policy strategies. Specifically, we increase the standard deviation of the price mark-up shock by 40% and lower that of the risk premium shock by 60%. Table 4 reports results under this calibration of the size of the shocks.

PLT outperforms IT in terms of inflation stabilization, followed by AIT and TPLT. PLT performance strongly deteriorates in terms of output stabilization. The output gap is relatively small but unstable, because PLT commands low (high) levels of the policy rate when output is high (low) and, thus, generates procyclical effects. AIT and TPLT are in-between IT and PLT for inflation stabilization. They perform better than both IT and PLT in terms of output stabilization, because both of them are much less procyclical than PLT and, thus, reduce output gap and volatility to a larger extent. Overall, TPLT and AIT show the lowest losses, followed by PLT and IT.

3.4 The role of inflation expectations

The effectiveness of PLT, AIT, and TPLT in stabilizing inflation strongly depends on the degree of forward-lookingness of inflation expectations. For example, following a disinflationary shock, the anticipation of a future temporary inflation target overshooting contributes to stabilizing current inflation. If this anticipation effect weakens, the effectiveness of the considered strategies can decrease. Thus, in the simulations reported in the next section (Section 3.4.1) we decrease the degree of forward-lookingness of inflation expectations by increasing the degree of indexation of current inflation to previous-period inflation and, simultaneously, decreasing the indexation to the long-run inflation target. The increased indexation of prices to past inflation makes price dynamics more persistent and less influenced by the adjustment of expectations, thus implying a possibly weakened effectiveness of monetary policy strategies that rely on anticipation effects.

Moreover, in a low inflation environment, when realized inflation has been below the target for a prolonged period of time, it may be possible that agents form inflation expectations by relying more on past observations than on forward-looking expectations. Ehrmann (2015) shows that when inflation is persistently low, expectations are more dependent on lagged inflation, and suggests that central banks should expect inflation expectations to behave differently under such circumstances than when inflation is close to target. If inflation expectations do not respond as assumed to central bank announcements, then the considered policies could be less effective during ELB periods. For this reason, different from previous sections where we considered fully rational (i.e., model-consistent) expectations, we also consider the case of "hybrid" inflation expectations, i.e. a weighted-average of two forecasts, adaptive and fully rational (Section 3.4.2).

3.4.1 Higher inflation indexation to past inflation

We consider the case of a higher parameter of inflation indexation to previous-period inflation, set to 0.5 instead of 0.4 (benchmark calibration). Table 5 reports the results. Relative to the benchmark case (Table 3), ELB frequency and duration increases under each strategy. Firms, when setting prices in a given period, anticipate to a less extent that inflation will return to its target in the long run and, instead, take relatively more into account previous-period inflation, which is relatively low. The implied higher real interest rate induce households and firms to reduce aggregate demand. The output gap increases. As a result, inflation and output gap means and volatilities increase under all considered regimes, and all the corresponding losses increase. However, the ranking does not change. PLT, AIT and TPLT continues to outperform IT.

3.4.2 Hybrid expectations

In all the previous simulations we have assumed that households and firms have model-consistent expectations and, thus, fully understand the policy strategy that is in place. In this respect, results allow us to assess the economy behavior once the strategy has been in place for some time, and not in the immediate aftermath of the announcement or adoption of such a policy.

Following Gelain et al. (2019), hybrid expectations are a weighted-average of two adaptive and fully rational (i.e., model-consistent) expectations:

$$\hat{E}_t\pi_{t+1} = \omega F_t\pi_{t+1} + (1-\omega)E_t\pi_{t+1}, \tag{9}$$

where ω $(0 \leq \omega \leq 1)$ is the weight of the adaptive component and can be interpreted as the fraction of households who employ the adaptive forecast rule for inflation. We assume hybrid expectations only for inflation. This allows us to focus on one specific channel, i.e. the price setting decision of firms, and analyze the implications of alternative expectations for the monetary policy transmission mechanism. The assumption could be extended to all model variables. We do not pursue this route here, for the sake of clarity. In equilibrium, the fully-rational forecast $E_t\pi_{t+1}$ takes into account the influence of households who employ the adaptive forecast rule.[19] The term F_t represents the adaptive expectation, which evolves according to the following equation:

$$F_t\pi_{t+1} = F_{t-1}\pi_t + \lambda_\pi(\pi_t - F_{t-1}\pi_t), \tag{10}$$

where λ_π $(0 < \lambda_\pi \leq 1)$ is a parameter and the term $(\pi_t - F_{t-1}\pi_t)$ is the observed forecast error in period t. The parameter λ_π measures the strength of the response to the most recent forecast error of inflation. The equation implies that the adaptive forecast at time

[19] See Gelain et al. (2019) for a full description and explanation of this form of hybrid expectations.

t is an exponentially-weighted moving-average of past observed values of inflation, where λ_π governs the distribution of weights assigned to past observed values, analogous to the gain parameter in the adaptive learning literature. When $\lambda_\pi = 1$, households employ a simple random walk forecast. We calibrate ω to 0.7 and λ_π to 0.1, values in line with those estimated by Gelain et al. (2019).

Fig. 5 reports impulse responses for the case of a recessionary demand shock (a positive risk premium shock). The first (top) row reports the impulse responses if expectations are model-consistent and the second (middle) row if inflation expectations are hybrid. The third row shows the impulse responses if inflation expectations are hybrid and the size of the shock is recalibrated so that, under IT, the number of periods at the ELB is the same as in the case of model-consistent expectations. The latter case allows us to "level the playing field" and, thus, to better compare the stabilization properties of the monetary policy strategies *for a given ELB duration* under the alternative assumptions of model-consistent and adaptive expectations.

The comparison of the first and second row reveals the role of the anticipation effect of the same recessionary demand shock. Under IT, the inflation rate decreases to a lower extent and in a more inertial way if inflation expectations are hybrid rather than model-consistent. The lower anticipation implies that current inflation does not greatly incorporates expected future inflation and expected future marginal costs. Inflation is more inertial, because hybrid expectations have a large backward-looking component. Output decreases by more than under hybrid expectations, because firms adjust prices and output to a smaller and larger extent, respectively. Consistent with the lower drop in inflation, the policy rate decreases less than under model-consistent expectations, and it does not even reach the ELB. The lower anticipation effect reduces the effectiveness of PLT, because it lowers the stabilizing effect of the expected future inflation overshooting on current inflation. Thus, inflation stays below its target level and output decreases slightly more than under model-consistent expectations. Under AIT and hybrid expectations, inflation and output decrease less and more than under model-consistent expectations, respectively. Both variables return to their baseline levels in a faster way than under IT, consistent with the stabilization properties of AIT (which is a make-up strategy). For TPLT, responses are the same as those under IT, because the ELB is not achieved in the IT case and, thus, there is no temporary switch from IT to PLT (thus, IT and TPLT lines coincide).

The lower anticipation effect under hybrid expectations makes responses more similar and closer across regimes. The ranking, however, does not change. The two make-up strategies, PLT and AIT, continue to be more effective that IT.

We further assess the properties of the considered strategies by reporting in the third (bottom) row of the chart the responses of the main variables when the ELB, under hybrid expectations and IT, is binding for the same number of periods as in the case of model-consistent expectations. Interestingly, and consistently with the lower anticipation effects, under PLT the policy rate has to decrease much more than in the case of model-consistent expectations to stabilize prices. Regardless of the monetary policy strategy followed by the central bank, output decreases to a larger extent than under model-consistent inflation expectations.

Overall, under hybrid inflation expectations and a recessionary demand shock, make-up strategies are more effective than IT in stabilizing inflation and output, even if to a lower extent than under model-consistent expectations.

Results for the case of the positive supply shock (i.e., the negative price mark-up shock), that simultaneously decreases inflation and increases output, are reported in Fig. 6 (the structure of the charts is the same as that of Fig. 5). Under hybrid inflation expectations, PLT calls for a larger and more prolonged reduction in the policy rate than under model-consistent expectations (compare the second and the first rows of Fig. 6). Under PLT, differently from IT, the policy rate hits the ELB and stays longer at the ELB. Moreover, relative to the case of model-consistent expectations, under PLT the policy rate stays at the ELB longer. Under PLT and hybrid expectations, the low policy rate implies that output increases to a larger extent than under model-consistent expectations.

With hybrid expectations the response of inflation is similar across monetary policy strategies. Inflation decreases less than under model-consistent expectations, because of the lower anticipation effect. The reduced anticipation effect favours IT because current inflation reflects expected future inflation to a smaller extent, while it damages makeup strategies, whose effectiveness depends on the stabilizing effects of future inflation target overshooting on current inflation. As for output, under PLT it increases relatively more if expectations are hybrid rather than model-consistent.

The third row shows responses under the assumption that inflation expectations are hybrid and the shock is recalibrated so that, in the case of IT, the policy rate hits the ELB for the same number of periods as under model-consistent expectations. Under hybrid expectations and PLT, the policy rate hits the ELB, compensates the lower positive anticipation effect and positively affects inflation. The response of inflation is rather similar across regimes, given that under IT the inflation rate decreases by less. Still, the decrease in inflation under PLT is smaller than under IT, and under AIT inflation returns to its baseline level at a faster rate than under IT. At the same time, output increases more than under model-consistent expectations in all regimes and, in particular, in the case of PLT and other makeup strategies.

Overall, in the case of a disinflationary mark-up shock and hybrid expectations, makeup strategies continue, as in the case of model-consistent expectations, to be effective in stabilizing inflation, at the cost of a somewhat more procyclical response of output.

4 Conclusions

Monetary policy strategies that central banks can use to commit to make-up for past inflation misses, such as price level targeting and its temporary version, are superior to inflation targeting in terms of reducing the likelihood and duration of periods in which the policy rate is at its effective lower bound. The two strategies are also superior to inflation targeting with regards to mean and volatility of inflation and output. An average inflation targeting strategy performs better than the simple IT, but worse than strategies targeting the price level.

The results of this study should be interpreted with caution. As for any model, its structure and calibration are imperfect approximations of the actual economy. Moreover, the relative incidence of shocks could be different than the one we have used in the simulations. More importantly, we have not considered the time inconsistency and the communication challenges associated with the adoption of alternative strategies.

The analysis can be extended along several dimensions. First, the interaction and possible synergies among the considered Taylor-type rules and non-standard measures, such as asset purchases. Second, the banking sector could be included, as the interaction of the ELB with banks' balance sheet could have non-trivial implications for the propagation of shocks and, thus, for the transmission of the monetary policy. Third, the model can be extended to assess the role of the exchange rate channel of monetary policy transmission mechanism. We leave these important issues to future research.

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Table 1: Steady-state equilibrium

Variable	Value
Inflation rate (400*($\overline{\pi}$-1))	2.0
Nominal interest rate (400*($\overline{R}$-1))	2.0
Real interest rate	0.0
Private consumption	60.0
Public consumption	20.0
Investment	20.0

Note: inflation, growth, and interest rates are reported as net annualized percentage point values. Private consumption, public consumption, and investment as % of GDP.

Table 2: Calibration

Parameter	Value
Monetary policy	
Interest rate smoothing (ρ_r)	0.867
Response to inflation (ρ_π in IT and TPLT)	1.9
Response to price level (ρ_p in PLT)	1.9
Response to cumulated inflation shortfall (ρ_{tpl} in TPLT)	1.9
Response to average inflation (ρ_π^{avg} in AIT)	1.9
Response to output growth (ρ_y)	0.15
Preferences	
Elasticity of intertemporal substitution	1
Discount factor	0.99999
Habit in consumption	0.57
Frisch labor elasticity	0.667
Technology	
Share of capital in production	0.24
Capital depreciation rate	0.025
Investment adjustment cost	3.0
Elasticity of substitution (goods)	6.0
Elasticity of substitution (labor)	4.3
Nominal rigidities	
Price stickiness (Rotemberg)	120
Wage stickiness (Rotemberg)	300
Inflation indexation to previous-period inflation	0.40
Wage indexation to previous-period inflation	0.64
Shock persistence (AR(1) coefficient)	
Risk premium	0.9
Price mark-up	0.9

Table 3: Benchmark results

	IT (without ELB)	IT	PLT	AIT	TPLT
ELB Frequency	21.9	20.2	15.7	14.8	12.5
ELB Duration	5.2	4.6	3.7	3.2	2.8
Mean(400*π)	2.1	1.1	2.0	1.5	2.0
$\sigma(400 * \pi)$	2.0	3.8	0.7	3.0	2.5
Mean(π_4)	2.1	1.2	2.0	1.6	2.0
$\sigma(\pi_4)$	1.9	3.3	0.6	2.7	2.3
Mean(y)	-0.1	-2.0	-0.3	-1.2	-0.8
$\sigma(y)$	3.1	5.1	3.2	4.9	3.9
Mean(R)	2.3	2.7	2.3	2.3	2.6
$\sigma(R)$	2.3	2.1	1.6	1.6	1.8
Loss($\mathcal{L}$)	9.1	27.4	5.7	21.0	13.9

IT: inflation targeting; PLT: price level targeting; TPLT: temporary price level targeting; AIT: average inflation targeting. ELB Frequency: frequency of ELB episodes (% of simulated periods); ELB Duration: mean duration of ELB (quarters); Mean(π): mean inflation rate level (annualized pp); Mean(y): mean output (% deviation from steady state); $\sigma(\pi)$: standard deviation of inflation (annualized pp); $\sigma(y)$: standard deviation of output; Mean(R)= mean nominal interest rate level (annualized pp); $\sigma(R)$: standard deviation of nominal interest rate; Loss $\mathcal{L} = \sigma^2(\pi) + \lambda_y \sigma^2(y)$, $\lambda_y = 0.5$. For each rule, we perform a set of 1000 stochastic simulations in which the economy is subject to different realizations of shocks, with each rule subject to the same cocktail of shocks. Within each stochastic simulation, statistics are tabulated for 100 quarters following initialization at steady state and a 100 quarter burn in.

Table 4: Larger size of price mark-up shocks

	IT	PLT	AIT	TPLT
ELB Frequency	10.6	10.7	4.1	3.8
ELB Duration	2.4	2.7	0.9	1.0
Mean(400*π)	1.7	2.0	2.0	2.2
$\sigma(400 * \pi)$	2.3	0.8	1.6	1.5
Mean(π_4)	1.7	2.0	2.0	2.3
$\sigma(\pi_4)$	2.1	0.6	1.4	1.3
Mean(y)	-0.8	-0.3	-0.2	-0.2
$\sigma(y)$	3.9	4.3	3.7	3.4
Mean$(400 * (R-1))$	2.3	2.2	2.1	2.4
$\sigma(400 * (R-1))$	1.5	1.5	1.1	1.3
Loss($\mathcal{L}$)	12.9	9.9	9.2	8.1

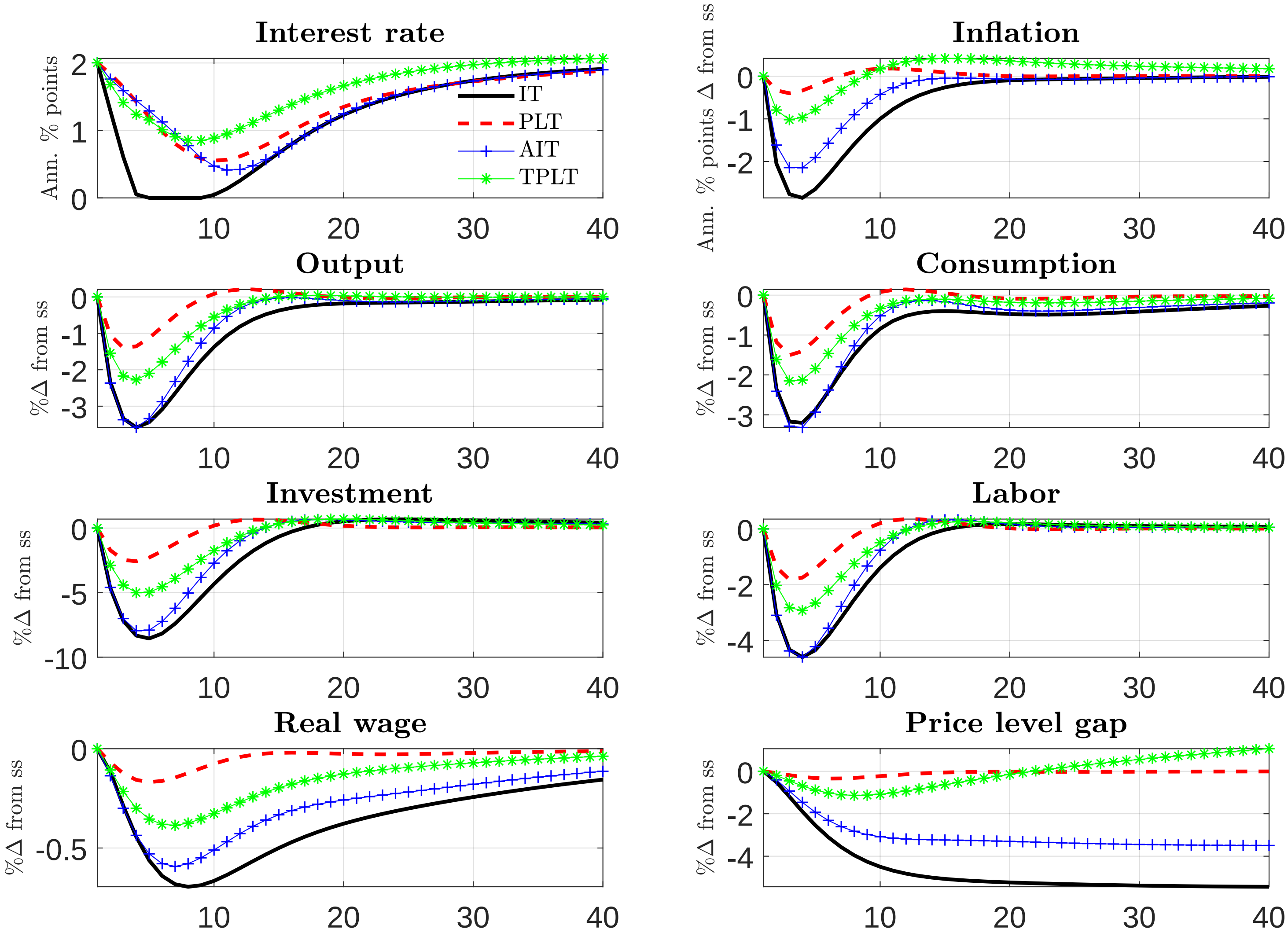
IT: inflation targeting; PLT: price level targeting; TPLT: temporary price level targeting; AIT: average inflation targeting. ELB Frequency: frequency of ELB episodes (% of simulated periods); ELB Duration: mean duration of ELB (quarters); Mean(π): mean inflation rate level (annualized pp); Mean(y): mean output (% deviation from steady state); $\sigma(\pi)$: standard deviation of inflation (annualized pp); $\sigma(y)$: standard deviation of output; Mean(R)= mean nominal interest rate level (annualized pp); $\sigma(R)$: standard deviation of nominal interest rate; Loss $\mathcal{L} = \sigma^2(\pi) + \lambda_y \sigma^2(y)$, $\lambda_y = 0.5$. For each rule, we perform a set of 1000 stochastic simulations in which the economy is subject to different realizations of shocks, with each rule subject to the same cocktail of shocks. Within each stochastic simulation, statistics are tabulated for 100 quarters following initialization at steady state and a 100 quarter burn in.

Table 5: Higher price indexation

	IT	PLT	AIT	TPLT
ELB Frequency	20.2	16.2	15.3	12.7
ELB Duration	4.7	3.8	3.3	2.9
Mean(400*π)	1.0	2.0	1.4	2.0
$\sigma(400 * \pi)$	4.0	0.7	3.2	2.6
Mean(π_4)	1.2	2.0	1.5	2.0
$\sigma(\pi_4)$	3.5	0.6	3.0	2.4
Mean(y)	-2.1	-0.3	-1.4	-0.9
$\sigma(y)$	5.2	3.3	5.1	4.0
Mean$(400 * (R-1))$	2.7	2.3	2.4	2.6
$\sigma(400 * (R-1))$	2.1	1.6	1.6	1.9
Loss($\mathcal{L}$)	29.4	5.9	23.7	14.7

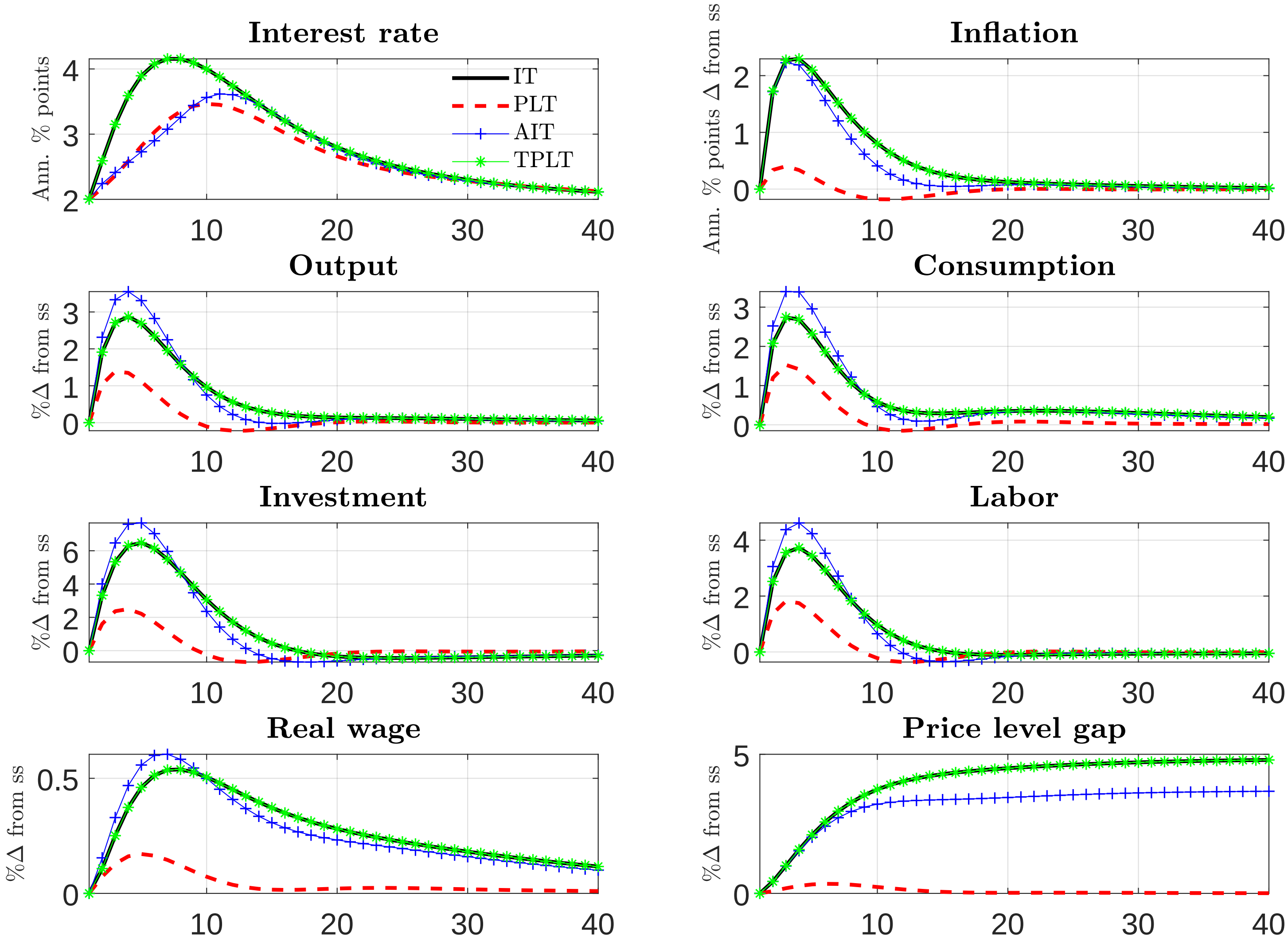
IT: inflation targeting; PLT: price level targeting; TPLT: temporary price level targeting; AIT: average inflation targeting. ELB Frequency: frequency of ELB episodes (% of simulated periods); ELB Duration: mean duration of ELB (quarters); Mean(π): mean inflation rate level (annualized pp); Mean(y): mean output (% deviation from steady state); $\sigma(\pi)$: standard deviation of inflation (annualized pp); $\sigma(y)$: standard deviation of output; Mean(R)= mean nominal interest rate level (annualized pp); $\sigma(R)$: standard deviation of nominal interest rate; Loss $\mathcal{L} = \sigma^2(\pi) + \lambda_y \sigma^2(y)$, $\lambda_y = 0.5$. For each rule, we perform a set of 1000 stochastic simulations in which the economy is subject to different realizations of shocks, with each rule subject to the same cocktail of shocks. Within each stochastic simulation, statistics are tabulated for 100 quarters following initialization at steady state and a 100 quarter burn in.

Figure 1: Positive risk premium shock



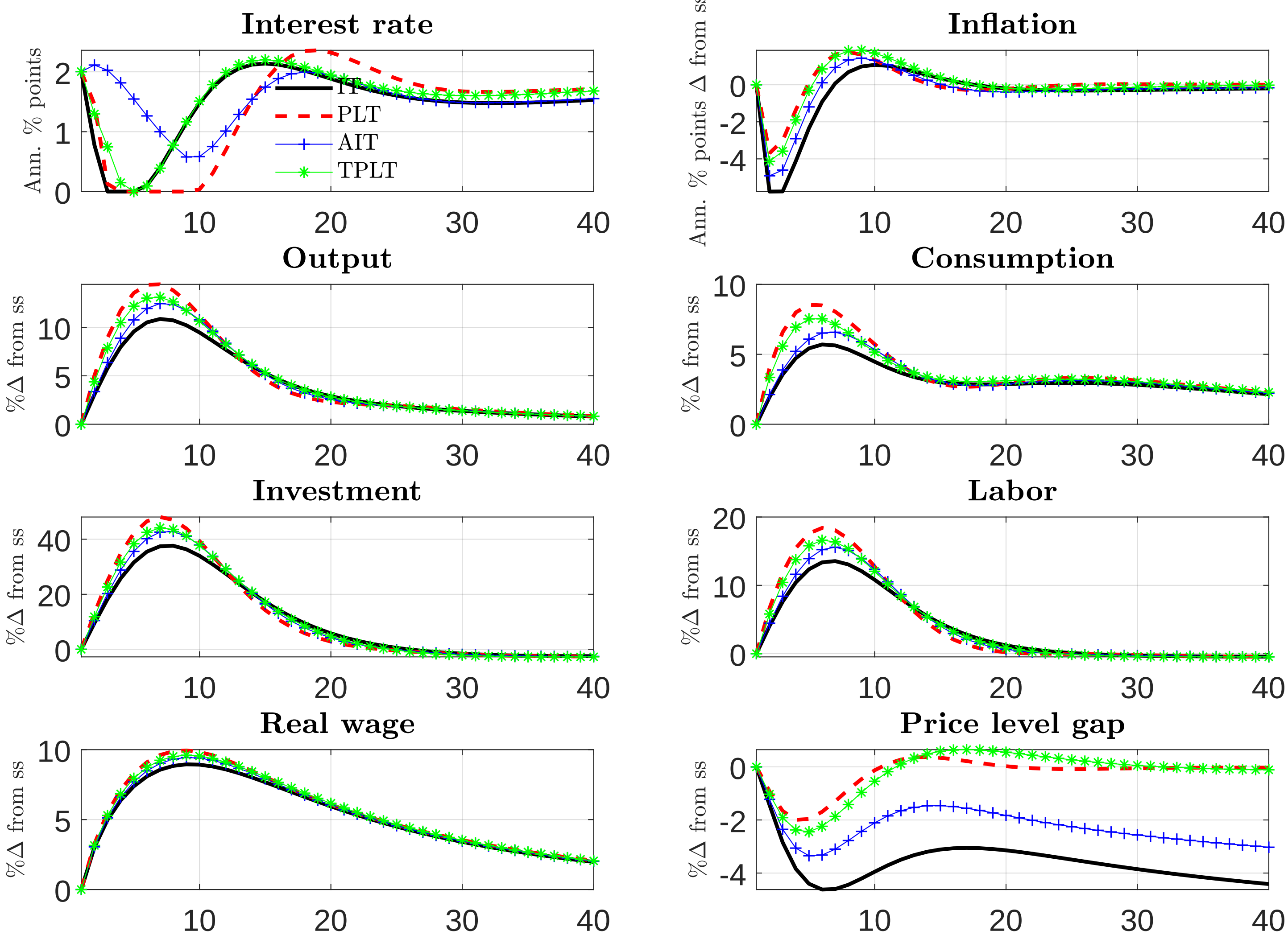
Notes: quarters on the horizontal axis; on the vertical axis, % deviations from the baseline; inflation rate: annualized pp deviations; interest rate: annualized pp, level.

Figure 2: Negative risk premium shock



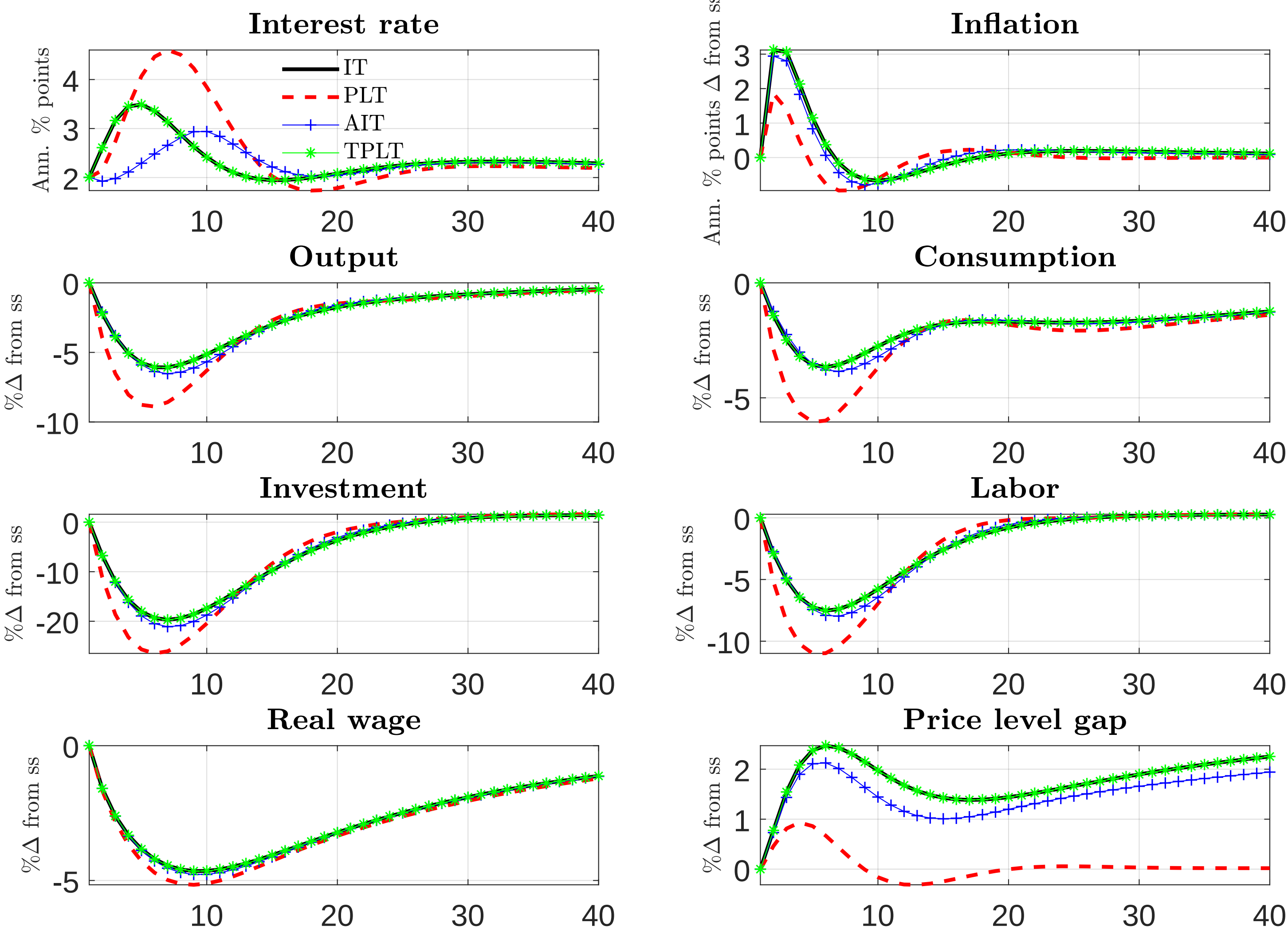
Notes: quarters on the horizontal axis; on the vertical axis, % deviations from the baseline; inflation rate: annualized pp deviations; interest rate: annualized pp, level.

Figure 3: Negative price mark-up shock



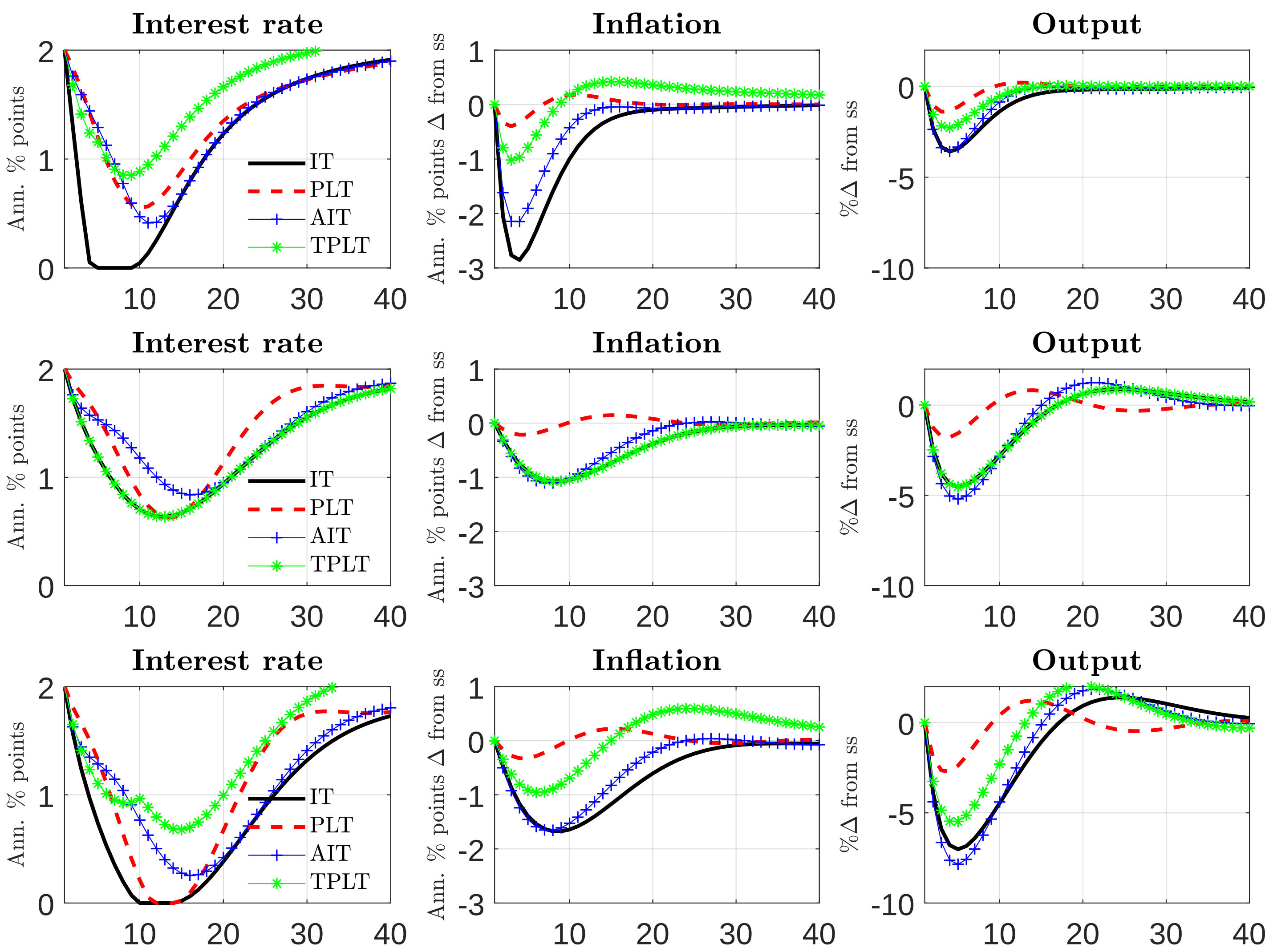
Notes: quarters on the horizontal axis; on the vertical axis, % deviations from the baseline; inflation rate: annualized pp deviations; interest rate: annualized pp, level.

Figure 4: Positive price mark-up shock



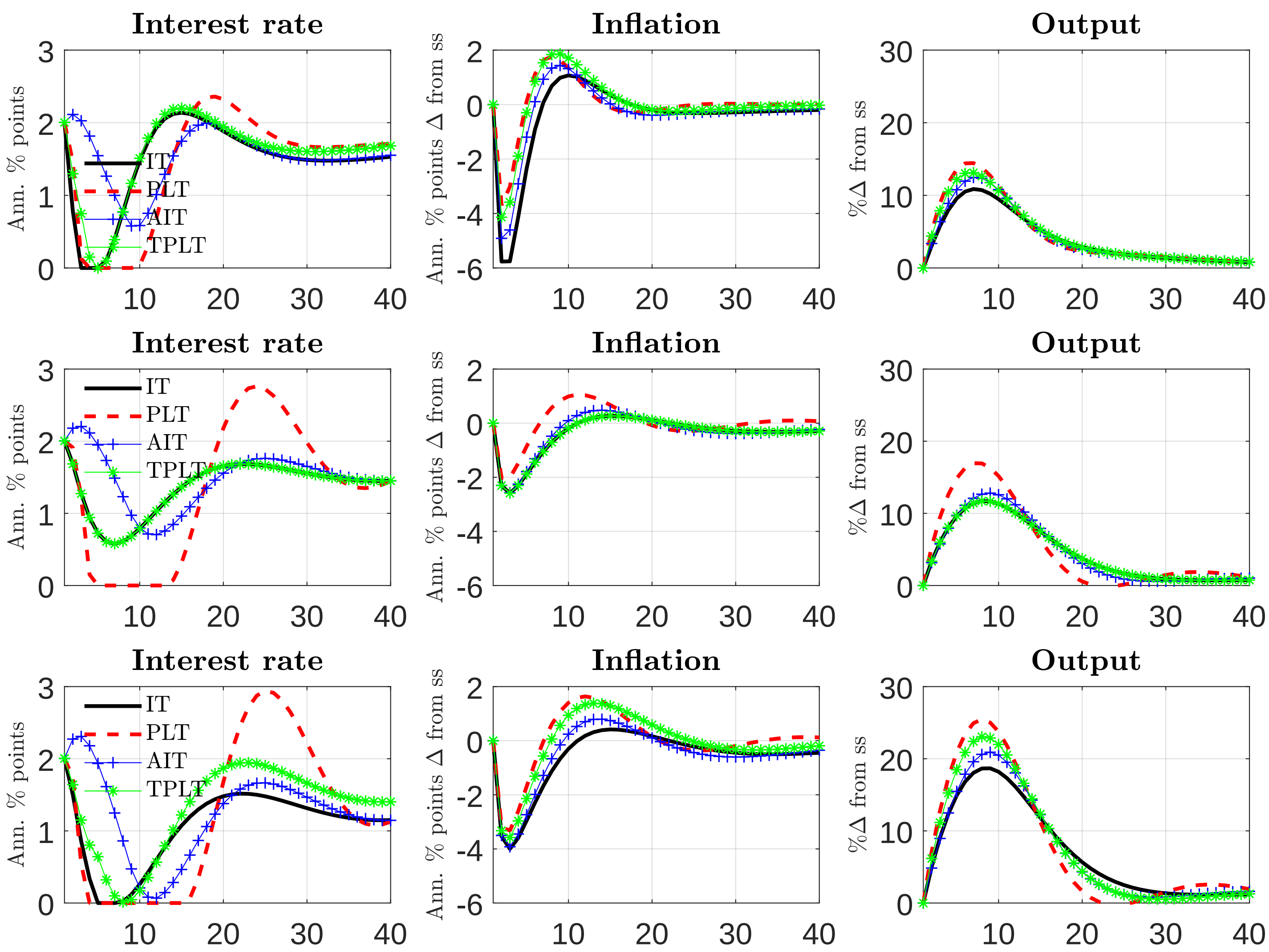
Notes: quarters on the horizontal axis; on the vertical axis, % deviations from the baseline; inflation rate: annualized pp deviations; interest rate: annualized pp, level.

Figure 5: Hybrid expectations: negative risk premium shock



Notes: quarters on the horizontal axis; on the vertical axis, % deviations from the baseline; inflation rate: annualized pp deviations; interest rate: annualized pp, level. In the first row we report responses under the assumption of model-consistent expectations; in the second row, under the assumptions of hybrid inflation expectations; in the third, it is assumed that inflation expectations are hybrid and the size of the shock is calibrated so that the duration of the ELB is the same as under model-consistent expectations (first row).

Figure 6: Hybrid expectations: negative price mark-up shock



Notes: quarters on the horizontal axis; on the vertical axis, % deviations from the baseline; inflation rate: annualized pp deviations; interest rate: annualized pp, level. In the first row we report responses under the assumption of model-consistent expectations; in the second row, under the assumptions of hybrid inflation expectations; in the third, it is assumed that inflation expectations are hybrid and the size of the shock is calibrated so that the duration of the ELB is the same as under model-consistent expectations (first row).

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