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MONETARY POLICY TIGHTENING IN RESPONSE TO UNCERTAIN STAGFLATIONARY SHOCKS: A MODEL-BASED ANALYSIS

by Anna Bartocci*, Alessandro Cantelmo, Alessandro Notarpietro* and Massimiliano Pisani*

Abstract

We evaluate the 'robust' monetary policy rate tightening in response to a stagflationary shock of uncertain magnitude using a medium-scale New Keynesian model. Under uncertainty, the tightening should generally be milder than under no-uncertainty in order to 'perform well' in different states of the world. The results hold true especially when financial tensions materialize under an excessive tightening of monetary policy. On the contrary, if the policy response to large stagflationary shocks is perceived as insufficient in a context of high inflation persistence, then the tightening of monetary policy should be as strong as in the case of no uncertainty.

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* Bank of Italy, Directorate General for Economics, Statistics and Research.

1 Introduction[1]

After a prolonged period of low inflation and interest rates, the rapid and persistent surge in inflation in advanced economies since 2021 has spurred a debate on the characteristics of the monetary policy response needed to stabilize inflation and macroeconomic conditions. The pace and magnitude of the restriction depend on the type and the size of the inflationary shock. However, a large degree of uncertainty surrounds the intensity of the inflationary shock, in particular in the case of those advanced economies severely hit by the shock to the international prices of energy commodities (a stagflationary shock). Such elevated uncertainty makes monetary policy decisions more challenging than in normal times. In particular, it entails the risks of excessively lax or excessively restrictive monetary policy responses to the stagflationary shock (that, thus, would not be consistent with macroeconomic and price stability).

In this paper, we use a closed-economy medium-scale New Keynesian model to evaluate the "robust" tightening of monetary policy (from an ex-ante perspective) in response to stagflationary shocks of uncertain magnitude. Intuitively, the response of monetary policy should be the most robust to the considered range of plausible scenarios, i.e., it should "perform well" in a number of different possible states of the world. We assume that three alternative sequences of stagflationary cost-push shocks, which differ in their average magnitude, could hit the economy.[2]

We simulate nine scenarios, characterized by different paths of policy rate tightening and sequences of cost-push shocks. Conditional on each possible sequence of stagflationary cost-push shocks, we initially compute the maximum level to which the central bank should gradually raise the policy rate (the so-called "terminal" rate) in order to bring inflation on target in the medium term and then we evaluate, for each policy rate tightening, a loss function, which features the squared deviations of inflation from the central bank target and of output from its long-run level. The robust tightening is then chosen according to the minimax criterion or the Bayesian approach. In the former case, it is the policy rate level whose worst possible outcome across different scenarios, in terms of inflation and output stability, is the minimal across the possible

[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 two anonymous referees, Michele Caivano, Stefano Neri and seminar participants at the Bank of Italy for useful comments. All remaining errors are ours.

[2]Our scenarios are illustrative and do not aim at describing the current and future macroeconomic outlooks or monetary policy choices of any specific advanced economy.

policy rate paths. In other words, it “insures” against the risk of very bad outcomes. In the latter case, it is the rate that minimizes the expected loss function, i.e., a weighted average of the loss function values, one for each sequence of stagflationary shocks, where each weight is the probability that each sequence of stagflationary shocks materializes.

To further characterize possible risks and worst scenarios, we consider the two cases of an excessively lax and excessively aggressive monetary tightening. We perform the same simulations, under two different assumptions about unintended consequences that could be triggered by each of those patterns. First, it is assumed that wage- and price-setting decisions are indexed to past inflation and do not take into account the central bank target (thus generating intrinsic inflation persistence) when the the central bank responds weakly to the sequence of stronger cost-push shocks. We try to capture, in stylized way, the risk that if the central bank does not raise the policy rate by a sufficient amount in response to strong stagflationary shocks, then medium-term inflation expectations could become less anchored to the central bank target and, thus, inflation dynamics could turn out to be intrinsically more persistent (the policy response to large stagflationary shocks is perceived as “insufficient” by households and firms). Second, we consider the case of an excessively aggressive monetary policy restriction in response to mild and medium cost-push shocks, which could induce an unnecessary tightening of financing conditions with negative implications for aggregate demand and inflation.

Finally, we perform a sensitivity analysis in which we assume a lower degree of nominal price rigidity in the presence of stagflationary shocks, to account for the evidence provided in recent contributions that the frequency of price adjustments significantly increases when the economy is affected by large shocks.[3]

Our results are the following ones. Under uncertainty the tightening should be generally milder compared to the case in which there is no uncertainty about the magnitude of the stagflationary shocks. In other words, when the central bank is uncertain about the magnitude of the stagflationary shocks, a robust-control approach suggests that it should raise the policy rate by less than it would do if it knew exactly which sequence of the cost-push shocks would eventually materialize. A milder tightening turns out to “perform well” across the considered different pos-

[3]See Cavallo et al. (2023).

sible states of the world. Results hold true in particular if financial tensions materialize under an "excessive" tightening of monetary policy. Instead, if the policy response to large stagflationary shocks is perceived as "insufficient" (i.e., excessively weak) in a context of high inflation persistence, then the tightening should be as high as in the case of no uncertainty, to avoid the risks of second-round effects. Our results are robust to the assumption of relatively low nominal price rigidity in the presence of large stagflationary shocks.

Our paper contributes to the existing literature on the consequences of parameter uncertainty for interest rate setting, with a specific focus on the case of uncertainty about the magnitude of a specific shock (of stagflationary nature). The very first contribution is Brainard (1967), which suggests that in response to exogenous shocks to the economy and in the presence of multiplicative parameter uncertainty it is often optimal for policymakers to change their instrument by less than would be optimal if all parameters were perfectly known ("Brainard conservatism principle"). Giannoni (2002) models uncertainty about key parameters and derives a robust minimax policy that is implemented by a simple instrument rule. Results imply that the policymaker responds more strongly to inflation than under certainty. Coenen (2007) simulates a New Keynesian model under the assumptions that inflation persistence is high and that there is considerable uncertainty about the prevailing degree of inflation persistence. The implied optimized interest-rate policies are characterized by a relatively aggressive response to inflation developments and exhibit a substantial degree of inertia. Similarly, Söderström (2002) shows that uncertainty about the endogenous inertia that characterizes inflation dynamics calls for a more aggressive policy response. Williams (2013) simulates a stylized macroeconomic model in a deflationary scenario resembling the aftermath of the 2007 global financial crisis and finds that the optimal monetary policy under parameter uncertainty is more muted in its response than optimal policy absent uncertainty. As a result, output and inflation return to target levels only gradually. Ferrero et al. (2019) relax, in a stylized New Keynesian model, the assumption of full central bank information by allowing for uncertainty on the model parameters and by assuming asymmetric information (the private sector observes the realizations of the random process of the parameters as they occur, while the central bank observes them with a one-period delay). Under such assumptions they show that optimal monetary policy can be either more cautious or more aggressive than in the full information case, depending on the degree of persistence of the cost-push shock. For low levels of persistence, optimal policy should become more cautious. On the contrary, for high levels of persistence optimal policy should become more aggressive than in the full information case.

Consistent with these contributions, we evaluate the robust monetary policy responses under the assumption of the central bank acting under uncertainty. Specifically, we consider alternative monetary policy rate paths implied by the central bank deviations from the Taylor rule (i.e., alternative conducts of monetary policy) in order to stabilize inflation within a given time frame and in a context of high uncertainty on the parameter "size" of (stagflationary) shocks. In this sense, we consider "scenario" uncertainty, where each stagflationary scenario is characterized by a sequence of the shocks with a given average size. We therefore take a different approach relative to the literature on optimized interest rate rules, see e.g. Erceg et al. (2000) and Schmitt-Grohe and Uribe (2007), which considers shock uncertainty but does not consider parameter uncertainty. According to our results, an aggressive monetary policy response to inflation is the best policy only if the indexation-to-past inflation parameter is calibrated to a high value and output has a relatively low weight in the loss function. The reason is that high indexation to past inflation induces high inflation inertia. In this respect, the result is in line with those contributions that suggest aggressive responses to highly persistent inflationary shocks.

The paper is organized as follows. The next section illustrates the main model features. Section 3 describes the simulated scenarios. Section 4 discusses the results. Section 5 concludes.

2 Main model features

Our analysis is based on a (standard) closed-economy medium-scale New Keynesian model. In the following we provide a brief description of the model. Appendix A reports the full set of equations.

There is a continuum of households that maximize an intertemporal utility separable in consumption and labor, subject to a budget constraint. Households supply labor and physical capital to firms operating in the intermediate sector. Each household is the monopolistic supplier of a specific type of labor and sets her wage taking demand for her type of labor as given.

Households' consumption is subject to external habits, while households' accumulation of physical capital is subject to quadratic adjustment costs on investment changes.

There is a continuum of firms in the intermediate sector. Each firm produces an intermediate good according to a Cobb-Douglas production function in capital and labor. Moreover, each firm acts under monopolistic competition and, taking demand as given, sets the nominal price of the product.

Finally, there is a continuum of firms in the final sector that under perfect competition combines intermediate goods to produce final consumption and investment goods.[4]

The model features nominal wage and price stickiness. Households and firms producing intermediate goods set nominal wages and prices, respectively, subject to quadratic adjustment costs. Both wages and prices are indexed to previous-period consumer price inflation and to the central bank inflation target, with corresponding weights between 0 and 1 and adding up to 1. In the benchmark calibration we assume that prices and wages are mainly indexed to the central bank inflation target, with a relatively high weight. In an alternative calibration, to capture possible second-round effects, we raise the indexation of wages and prices to past inflation to a value close to one, so that inflation becomes highly persistent, while the central bank inflation target affects wage- and price-setting decisions to a lesser extent than in the benchmark case.

In all scenarios we assume that households, firms, and the central bank know the model equations, i.e., there is no uncertainty about model (mis-)specification and/or parameter values. All of the actors know the type of shock perturbing the economy, i.e., a stagflationary shock and, in some simulations, a risk-premium shock. Neither the private sector nor the central bank know the particular sequence of the shocks that will hit the economy. Moreover, as explained below, households and firms are also surprised by monetary policy decisions taken by the central bank in response to the supply shocks.

In what follows we illustrate nominal rigidities, the implementation of the monetary policy tightenings, and the calibration of the model.

[4]Each continuum (of households, intermediate-sector firms, and final-sector firms) has mass equal to one.

2.1 Nominal rigidities

On the firms' side, we assume that the generic firm in the intermediate sector operates under monopolistic competition and sets the nominal price of its goods to maximize the expected stream of profits subject to the demand for its product and, crucially, to nominal price stickiness, modeled as a quadratic price adjustment cost $AC_{i,t}$ in units of the final-good basket:

$$AC_{i,t} = \frac{\kappa_p}{2} \left(\frac{p_{i,t}/p_{i,t-1}}{\pi_{t-1}^{ind_p} \overline{\pi}^{1-ind_p}} - 1 \right)^2 P_t Y_t, \tag{1}$$

where $\kappa_p > 0$ is a parameter measuring the degree of nominal price stickiness, $p_{i,t}$ is the price of generic good i, $0 \leq ind_p \leq 1$ measures indexation of current-period prices to the previous-period gross inflation rate π_{t-1}, and $1 - ind_p$ to the steady-state gross inflation rate $\overline{\pi}$, assumed to be equal to the inflation rate target set by the central bank, P_t is the price of the final good basket, and Y_t is the final good basket.

Similar assumptions hold for households when setting their nominal wages.

In some simulations we will increase the value of the parameter ind_p (and of the corresponding parameter in the wage quadratic adjustment cost) to assess the impact of reducing the role of the central bank inflation target in price- and wage-setting decisions.

2.2 Monetary policy

In the simulations, it is assumed that three alternative sequences of unanticipated (by households, firms, and central bank) stagflationary (cost-push) shocks can affect the economy during the first twelve quarters. Importantly, the central bank and the private sector have no information about the stagflationary shocks and are surprised on a period-by-period basis. In response to each sequence of shocks, the central bank sets a gradual monetary policy rate tightening (up to the terminal level) to stabilize inflation at the target in the third year. Each of the three alternative policy rate paths is imposed through a sequence of restrictive monetary policy shocks, which surprise households and firms on a period-by-period basis. After each monetary policy shock, agents expect that, in the following periods, the central bank will set the policy rate in a gradual way (interest rate smoothing) according to a standard Taylor rule to stabilize consumer price inflation and economic activity. From the thirteenth quarter onwards, the Taylor rule is always active. Thus, consistent with the highly uncertain macroeconomic outlook, households and firms anticipate that the central bank will set the policy rate so that inflation is on target in the medium run, but they do not necessarily anticipate that it will be on target in the third year.

2.3 Calibration

The model is calibrated, for illustrative purposes, in line with the New Keynesian literature.

Table 1 reports the matched great ratios (private consumption, public consumption, investment in physical capital, all as a percentage of GDP) in the steady-state equilibrium.[5] The great ratios for the main macroeconomic variables broadly match evidence for the main advanced economies. Long-run inflation is set to the 2% in net annual terms, a value representing the target of the central bank. The nominal policy rate is 2%.

Table 2 contains the calibration of the parameters, chosen in line with the literature and to match quantities reported in Table 1.

The discount factor is set close to 1, in order to obtain a relatively low level of the natural rate of interest, given the inflation target.[6] The intertemporal elasticity of substitution is set to one (equivalent to log-utility). The consumption habit persistence parameter is set to 0.57 and the Frisch elasticity of labor supply to 0.667.

The elasticity of output with respect to capital in the Cobb-Douglas production function is set to 0.24 to match the investment-to-GDP ratio. The depreciation rate of capital is set to 0.025. The adjustment cost of investment in physical capital is set to 3.

Gross markups in the goods and labor markets are set to 1.2 and 1.3, respectively (the corresponding elasticities of substitution among goods and labor services varieties to 6 and 4.3, respectively).

Nominal price and wage rigidities parameters are set to 120 and 300, respectively, which

[5]In the steady-state equilibrium, wages and prices are flexible and the adjustment costs on investment in physical capital are zero.

[6]According to IMF (2023), "*[...] once the current inflationary episode has passed, interest rates are likely to revert toward pre-pandemic levels in advanced economies. How close interest rates get to those levels will depend on whether alternative scenarios involving persistently higher government debt and deficit or financial fragmentation materialize.*" For estimates of the US and EA natural rates of interest see also Neri and Gerali (2019).

correspond, if converted to Calvo (1983) terms, to a probability of not adjusting prices equal to 0.82 (i.e., prices are adjusted once every five quarters on average) and a probability of not adjusting wages equal to 0.75 (thus, the average length among wage adjustments is four quarters). Indexation to the previous-period consumer price inflation rate is set to 0.40 for prices and 0.64 for wages. In the monetary policy rule, the interest rate smoothing parameter is set to 0.87, the response to inflation to 1.9 and the response to output growth to 0.15. Similar values are reported in Coenen et al. (2018). Such values imply a response of prices and wages to a standard monetary policy shock in line with evidence for advanced countries. Details about the calibration of the cost-push shock are provided in Section 4.1.

3 Scenarios

To model the highly uncertain macroeconomic outlook, we assume that three alternative sequences of stagflationary (cost-push) shocks can hit the economy (we call them "medium", "milder", and "stronger" , respectively.) All agents in the economy, namely households, firms, and the central bank, do not know which of the three sequences will materialize and are surprised, on a period-by-period basis, by a new realization (of the single shock of the sequence).[7]

We compute the terminal level up to which the central bank should gradually raise the policy rate in order for inflation to be on average on target in the third year of simulation (the "medium run"), conditional on the realization of each alternative sequence of the cost-push shocks.

We evaluate the macroeconomic outcomes implied by the implementation of each of three policy rate tightenings under each of the three alternative sequences of cost-push shocks. For example, the same policy rate tightening that brings inflation on target under the medium cost-push shock is imposed also under the milder and stronger cost-push shocks, to assess its implications for inflation and output in correspondence of each of three sequences of shocks. A similar swap is applied to the other two policy rate profiles. Overall, we simulate nine (three times three) different scenarios, one for each possible sequence of policy rates and sequence of

[7]Specifically, we assume that the cost-push shock follows a stationary AR(1) process. All agents know the persistence parameter (set to 0.88 as reported in Table 1) and form their expectations on the future value of the shock based on such persistence and on the current innovation. Nonetheless, they are surprised by a new realization in each period, over a 3-year horizon.

cost push shocks.

We then compute for each monetary tightening and each sequence of cost-push shocks a standard quadratic loss function that features the squared deviations of inflation from the central bank target and output from its long run level. We evaluate the robustness of the tightening according to the minimax criterion and the Bayesian approach. According to the former, the robust tightening is therefore the one whose worst possible outcome across different scenarios, in terms of inflation and output stability, is the minimal across the possible policy rate paths. In other words, it "insures" against the risk of bad outcomes in terms of both inflation and output stability. According to the latter, it is the rate that minimizes the expected value of the losses, i.e., the weighted average of the loss function values, one for each sequence of stagflationary shocks, where each weight is the probability that each sequence of stagflationary shocks materializes.

To further characterize possible risks and worst scenarios, we perform the same computations under the assumptions of wage- and price-setting decisions indexed to past inflation, which would raise inflation persistence, in correspondence of an excessively lax response of the central bank to the sequence of stronger cost-push shocks. We also consider the case of an excessively aggressive monetary policy restriction, which could induce an unnecessary tightening of financing conditions and, thus, negative effects on aggregate demand. Finally, we perform a sensitivity analysis by allowing for lower nominal price rigidities in the presence of large stagflationary shocks.

4 Results

4.1 Cost-push shocks and policy rate tightening

Fig. 1 reports the responses of inflation and output under the alternative sequences of the stagflationary cost-push shock and the alternative tightenings of the monetary policy rate.

As a first step, we show, in the column labelled "Taylor" that under a systematic Taylor rule inflation would be above target in the third year in correspondence of each sequence of cost-push shocks. The calibration of the cost-push shocks realizations is illustrative (see Table 1). Under the"medium" cost-push shock and a systematic (Taylor rule-based) monetary policy response, inflation would be 0.6 percentage points (p.p.) above target in the third year. The central bank gradually raises the policy rate in response to this specific sequence of unexpected stagflationary shocks. Nonetheless, at a three-year horizon the response is not sufficient to bring inflation on target (the Taylor rule will bring inflation on target at a later stage, in the medium to long run).

Therefore, we compute an illustrative policy rate path (labelled "i1", see Column i1, black solid lines), implemented through a sequence of (monetary policy) shocks to the Taylor rule in the initial twelve quarters, which is sufficient to stabilize inflation on average at the three-year horizon if the medium sequence of cost-push shocks eventually materializes. Specifically, we assume a gradual (linear) increase in the policy rate up to some terminal level.[8] Compared to the first column, the higher interest rate implies a larger contraction in output.

After computing the policy rate path that brings inflation on target under the medium cost-push shock (i.e., i1), we show the macroeconomic effects of the very same policy rate path if the milder or the stronger cost-push shock sequences eventually materialize. We illustratively calibrate the size of the milder and stronger cost-push shocks such that, under the same policy rate path, inflation is 0.5 p.p. below or above target in the third year, respectively. The dynamics of inflation and output in these two possible scenarios, under the policy rate path i1, are reported in column "i1" (blue-dotted and red-dashed lines, respectively).

Under the milder and stronger cost-push shock sequences, the same policy rate increase i1 induces an undershooting and overshooting of the inflation target, respectively. Consistently, output decreases by more and less under the stronger and milder sequences than under the medium sequence, respectively.

Column i2 reports the impulse responses assuming the central bank raises the policy rate to "i2", i.e., the (terminal) level that brings inflation on target under the milder sequence of cost-push shocks (see blue dotted line in the inflation chart). The implied policy rate level is lower than under the medium sequence, consistent with the smaller dimension of the shocks. This rate path implies that inflation overshoots the target under both the medium and stronger sequences of cost-push shocks, as their sizes are larger than that of the milder sequence. Moreover, in correspondence of the milder sequence of cost-push shocks, inflation is larger than under the "i1"

[8] Without any restrictions, a multiplicity of interest rate paths would deliver inflation on target in the third year. Our characterization of the policy rate path is meant to be illustrative. We want to capture, in a stylized way, a gradual but steady increase in the policy rate up to some terminal level. Thus, we assume the same pace in the initial increase in the policy rate, and instead consider alternative terminal levels.

policy rate increase, as it can be seen by comparing the inflation charts of columns i2 and i1. However, for a given shock the decrease in output is, in absolute terms, smaller under the "i2" policy rate increase than under the "i1" increase.

Similarly, column i3 shows responses under the assumption that the policy rate path (labelled "i3") is the one consistent with the achievement of the inflation target under the stronger sequence of cost-push shocks (see red dashed line in the inflation chart). Given the larger rise in the policy rate, inflation undershoots the target if the medium and milder sequences of shocks occur and, in correspondence of the very same sequence, it is lower than under the "i1" and "i2" policy rate increases, as shown by the comparison of inflation charts across the three columns. The larger policy rate increase would also imply a larger output decrease than under the other two rate increases, as suggested by the comparison of output charts across the three columns.[9]

4.2 Evaluating robustness of monetary policy

The choice of the policy rate level under uncertainty about the size of the stagflationary shocks presents the risk of doing "too little" or "too much", as inflation could deviate from the target and output could decrease relative to the baseline.

To evaluate the different policy options under uncertainty we use a robust control approach. For each of the three alternative sequences of stagflationary shocks and each of the three policy rate tightening paths, we compute a loss function in period $t = 0$ (beginning of the simulations) that includes the quadratic deviations of inflation from the target and output from its steady-state value, computed over the first twelve quarters (the three-year horizon represents the medium term) and discounted with the households' discount factor β ($0 < \beta < 1$):[10]

[9] As said, the policy rate paths are implemented through a sequence of unexpected monetary policy shocks, while the Taylor rule is switched off. This technical solution allows us to keep the paths unchanged across the different scenarios (i.e., across the different realizations of the cost-push shocks). Even if implemented through exogenous monetary policy shocks, each policy rate path should be interpreted as a "reaction function" of the central bank that, conditional on one specific sequence of stagflationary cost-push shocks, induces inflation to hit the target three years after the start of the simulation. Importantly, such very specific "reaction function" is not systematic (in fact, after the third year the Taylor rule is newly activated) and not communicated to the public. Moreover, depending on the cost-push shocks realization, it may or may not be optimal in the sense of being sufficient to bring inflation on target at the three-year horizon.

[10] For an application of the quadratic loss function (to alternative monetary policy regimes) see Busetti et al. (2021). We have performed the same exercises reported in this section using a loss function computed over a 40-quarter horizon. The qualitative conclusions of our analysis are unchanged, since most of the action is concentrated in the initial three to four years. Afterwards, the effects of the cost-push shocks vanish and therefore the Taylor rule commands a similar behaviour of the policy rate across scenarios.

$$\mathcal{L}_{0,n}\left(i_j\right)=\sum_{t=0}^{11}\beta^t\left\{\omega_\pi\left[100\times\left(\pi_{n,t}\left(i_j\right)-\bar{\pi}\right)\right]^2+\omega_y\left[100\times\left(\frac{y_{n,t}\left(i_j\right)}{\bar{y}}-1\right)\right]^2\right\};j=1,2,3;n=1,2,3, \quad (2)$$

where j indexes the three monetary policy tightening paths, n indexes the three sequences of cost-push shocks, i.e., $n = 1$ (medium stagflation), 2 (milder stagflation), 3 (stronger stagflation), ω_π is the weight of inflation and ω_y the weight of output. In what follows, we normalize ω_π to one and allow ω_y to take values between 0 and 1.[11]

We carry out the loss function evaluation using the minimax and the Bayesian approaches.

4.2.1 Minimax approach

We initially select the "robust" policy rate tightening path according to the minimax approach, that is, the path (and, hence, the level) that minimizes the largest loss across the three considered scenarios (i.e., the three possible sequences of cost-push shocks):

$$i_j = arg\min\left[\max\mathcal{L}_{0,n}(i_j)\right]; j=1,2,3; n=1,2,3. \quad (3)$$

Fig. 2 shows the minimal maximum loss function in correspondence of each policy rate tightening as a function of the output weight ω_y.[12] Among the three tightening paths, i2 is the "robust" one, i.e., it generates the minimal maximum loss, followed by i1, in particular if the output weight is relatively large. The distance between the three losses increases with the output weight. The tightening i2 is consistent with inflation on target under the milder cost-push shock and the implied terminal value is lower than the corresponding terminal values under the levels i1 and i3. It implies a lower output loss than the other policy rate levels under the three considered sequences of cost-push shocks (see Fig. 1). To the opposite, the tightening i3, which is the highest among the three (in terms of the highest level reached by the policy rate), generates the largest output loss and, thus, the largest loss function, in particular for relatively high values of

[11] We do not include in the loss a quadratic term in the changes in the short-term nominal interest rate because, once the terminal level is reached, the policy rate remains there until quarter 12 by construction. Hence, in most periods the change in the policy rate is equal to zero.

[12] We have computed the loss functions also under the assumption of a lower discount factor β, set to 0.9994 instead of 0.99999 as in our (benchmark) calibration. Qualitatively, results do not change and are available upon request.

the output weight in the loss function.

The milder tightening is also no greater than the optimal tightening under no-uncertainty. In the latter case the central bank, knowing with certainty which of three scenarios will materialize, would choose, among the very same three policy rate paths, the one that stabilizes inflation in the third year. Thus, the selected interest rate path would be necessarily larger that or at most equal to the milder policy rate path.

In the limit case of $\omega_y = 0$ (i.e., the loss depends only upon the quadratic terms of inflation deviations from the target), the path i1 is the one with smallest maximum loss, while paths i2 and i3 which induce a larger target overshooting and undershooting, respectively. Differences in the associated loss functions are, however, very small, as shown in Figure 3. In this limiting case, the optimal path (i1) is not necessarily smaller than the optimal path under no-uncertainty, because the central bank would choose the path i2, whose policy rate values are smaller than i1's values, only if it is sure than the small cost-push shocks will materialize.

Overall, a relatively small tightening is preferable (according to the minimax criterion) if there is high uncertainty about the size of the stagflationary shock.[13] Moreover, under uncertainty the tightening should be generally milder compared to the case in which there is no uncertainty about the magnitude of the stagflationary shocks.

4.2.2 Bayesian approach

We now report the (expected) loss function computed according to the Bayesian approach, i.e., we consider, for each policy rate tightening, a weighted average of the loss function values, one for each sequence of stagflationary shocks, where each weight is the probability that each sequence of stagflationary shocks materializes:

$$E_0(\mathcal{L}(i_j)) = \sum_{n=1}^{3} \pi(n)\mathcal{L}_{0,n}(i_j); \quad j = 1, 2, 3, \tag{4}$$

[13] The central bank always raises the policy rate to stabilize inflation and economic activity in response to the stagflationary shocks. If the central bank kept the policy rate constant at its baseline level, by "looking through the shock", the loss would be larger than in the considered cases, because the shock is assumed to be rather persistent.

where $0 < \pi(1), \pi(2), \pi(3) < 1, \pi(1)+\pi(2)+\pi(3) = 1$, and $n = 1$ (medium stagflation), 2 (milder stagflation), 3 (stronger stagflation). We assume a Bayesian strategy with flat prior beliefs, i.e., the policymaker assigns the same probability $\pi(n) = 1/3$, to each sequence of stagflationary shocks consistent with high uncertainty surrounding the realizations of sequences of shocks.[14]

Fig. 4 reports the three loss functions. Results are similar to those obtained under the minimax approach. The lowest expected loss is the one associated with the smallest tightening, i2, while the highest expected loss is associated with the largest tightening i3. The distance among the losses is increasing in the output weight. Thus, increasing the policy rate up to a relatively low terminal value is preferable if the policymaker assigns the same prior probability to each sequence of stagflationary shocks. As in the case of the minimax approach, the milder tightening (i2) is no greater than the optimal tightening under no-uncertainty. In the latter case the central bank, knowing with certainty which of scenario occurs, chooses and interest rate path that is necessarily larger than, or at most equal to, i2.

We then assess to which extent the assigned probabilities affect the results by assuming that the probability $\pi(1)$ of the medium stagflation scenario is zero and, thus, that the probability of milder stagflation $\pi(2)$ is equal to one less the probability $\pi(3)$ of stronger stagflation, with the latter allowed to change between one and zero:

$$\pi(2) = 1 - \pi(3); \pi(1) = 0. \tag{5}$$

The purpose of this exercise is to characterize a situation in which the shocks realizations tend to assume rather extreme values. As shown in Fig. 5, the highest terminal rate, i3, is preferable only if the stronger sequence of cost-push shocks is extremely likely (i.e., it has a probability of realization roughly larger than 80%, thus under conditions of relative certainty about the realization of the most stagflationary sequence of shocks) *and* the output weight ω_y in the loss function is zero. However, Fig. 6 shows that even for relatively modest values of the output weight ($\omega_y = 0.1$) the largest tightening is the least preferable, because the central bank can achieve lower expected losses by choosing the small tightening i2 and, as a second-best, the

[14]See Levin and Williams (2003). The minimax approach does not place weights on the three sequences of shocks.

medium tightening i1.

Overall, also the Bayesian approach does not exclude that a prudent monetary policy tightening is preferable to the more aggressive ones if uncertainty is sufficiently high and the central bank attaches a non-zero weight to output volatility in the loss function.

4.3 Excessively lax and aggressive monetary policy responses to stagflationary shocks

Results reported above suggest that the central bank should not be as aggressive as in the no-uncertainty case in response to stagflationary cost-push shocks of uncertain size, irrespective of the robustness criterion it chooses to apply. Differently from the previous sections, it is assumed that wage- and price-setting are mainly indexed to past inflation and assign a very low weight to the central bank target (thus generating intrinsic inflation persistence) when the central bank responds weakly to the sequence of stronger cost-push shocks (the policy rate reaches level i1 or i2, but not i3, and thus inflation is not stabilized on average in the third year, see Fig. 1).[15] In all other scenarios, wage- and price-setting decisions are instead assumed to be mainly indexed to the central bank target (including the scenario in which the central bank's response to stronger cost-push shocks is sufficiently aggressive to guarantee that inflation hits the target, i.e., the terminal level of the policy rate is i3). These assumptions try to capture, in stylized way, the risk that if the central bank does not raise the policy rate by a sufficient amount in response to strong stagflationary shocks, then medium-term inflation expectations could become less anchored to the central bank target and, thus, inflation dynamics could turn out to be *intrinsically* more persistent.

We also consider the case of an excessively aggressive monetary policy restriction, which could induce an unnecessary tightening of financing conditions. Excessive financial amplification of the restrictive monetary policy impulse, by negatively affecting aggregate demand, could jeopardize macroeconomic and (medium-term) price stability. To take into account financial

[15]Specifically, we set the parameters ind_p in Eq. 1 and ind_w (the parameter $0 < ind_w < 1$ measures the weight of past inflation in the quadratic wage-adjustment cost) to 0.95, a relatively high value (the corresponding weights of the central bank target, $1 - ind_p$ and $1 - ind_w$, are thus low). Importantly, all agents know the correct values of the indexation parameters. Hence, similar to the previous case, uncertainty only pertains to the realization of the shocks.

amplification, we assume that, on top of the cost-push shocks, a financial shock materializes in correspondence of the central bank setting i3, i.e., the largest tightening, in response to the milder and medium sequence of stagflationary shocks (but not in response to the stronger sequence). The shock is modeled as an exogenous risk-premium shock. In these two cases i3 represents an excessive monetary tightening, because it implies an undershooting of the inflation target and reduces economic activity to a larger extent (see Fig. 1). The financial shock, instead, does not materialize under the other combinations of tightenings and sequences of cost-push shocks. The risk-premium shock induces a sudden 150bp increase in the short-term rate paid by the bond held by households which materializes only in the first period.[16] The central bank does not react to the shock in the initial period, (we assume it is surprised by it) and in the subsequent periods sets the policy rate to achieve the inflation target in the third year.

Fig. 7 reports the dynamics of the main macroeconomic variables. By assumption the policy rate paths are the same as in the corresponding benchmark case shown in Fig. 1. The inflation rate is instead larger if the policy rate tightenings i1 and i2 are implemented under the stronger stagflation scenario, as inflation becomes more inertial given that i1 and i2, different from i3, do not stabilize inflation in third year but induce an overshooting of the target. Similarly, inflation and output are lower than in the corresponding benchmark case (Fig. 1) if the tightening i3 is implemented under the milder and medium stagflation cases, because it is associated with financial tensions that reduce aggregate demand.

Fig. 8 reports the implied loss functions computed under the minimax approach. Different from the cases reported in previous sections, even if in some scenarios the policy rate path i3 (the largest among the three tightenings) might trigger a financial shock, it is now preferable to both tightenings i1 and i2 if inflation deviations from the target are the main determinants of the loss function, i.e., if the output weight in the loss is sufficiently low. The reason is that the tightenings i1 and i2 (both smaller than i3), joint with the the assumption of high indexation to past inflation, make inflation persistent and, thus, inflation deviations from the target relatively

[16]Table 1 reports the corresponding shock size. The shock multiplies the policy rate in the household's Euler equation. Thus, the short-term interest rate paid by the bond held by the households has a risk-free component (the policy rate) and a risk premium. In the initial quarter the risk premium shock is a wedge between the policy rate and the short-term rate. Starting from quarter two, the policy rate and the short-term rate coincide. Moreover, for simplicity we assume the same increase in the short-term rate both under the medium and milder stagflationary shocks. Appendix B shows the propagation of the risk-premium shock under the systematic Taylor rule.

large. Conversely, the financial shock triggered by implementing i3 under the milder or medium scenarios is akin to an aggregate demand shock, which reduces inflation and economic activity. When combined with the stagflationary cost-push shock, the net effects are a more contained increase in inflation and a larger decrease in economic activity. However, for a sufficiently low output weight, the maximum loss associated with i1 and i2 is above that associated with i3.

Fig. 9 shows the corresponding loss functions computed under the Bayesian approach, which assigns, as in the previous section, the same probability $\pi(n) = 1/3$, to each sequence of stagflationary shocks, consistent with high uncertainty surrounding the realizations of the sequences. Results are in line with those obtained under the minimax approach.

Overall, a relatively large tightening is preferable only if the realization of relatively large stagflationary shocks could be associated with high intrinsic inflation persistence and the central bank is mainly concerned about inflation stabilization. Otherwise a milder monetary policy restriction is preferable.

4.4 Lower nominal price rigidities and large stagflationary shocks

In the previous section we have allowed indexation to past inflation to increase under strong stagflationary shocks and the policy rate paths i1 and i2. Recent evidence in Cavallo et al. (2023) shows that the frequency of price adjustments significantly increases in response to large shocks. In order to account for this evidence, we check whether our results are robust to cases in which, under i1 and i2, a strong stagflationary shock is associated with more flexible prices.[17] Relative to Section 4.3, we replace the cases of stronger stagflation and high indexation to past inflation under i1 and i2 with the case of lower nominal price rigidities. We decrease the price adjustment cost parameter from 120 to 50, which amounts to reducing the average frequency of price adjustment from 5.5 to 3.7 quarters. Figure 10 reports the dynamic responses of inflation and output in these additional cases. With lower nominal price rigidities (this case is labelled "flexible prices" in the chart), the stronger stagflationary shocks induces, under the policy rate path i1, a more frontloaded increase in inflation, which reflects the more rapid price adjustment, and a corresponding smaller drop in output, compared to the case of high indexation. Over

[17]The degree of price indexation is set to its baseline value (0.4 for prices and 0.64 for wages).

a three-year horizon the increase in inflation is similar, but the fall in output is indeed more contained. A similar pattern is observed under the policy rate path i2. Figures 11 and 12 report the minimax and expected losses. Results are qualitatively unchanged compared to the case of high indexation.

5 Concluding remarks

This paper has provided an evaluation of the "robust" monetary policy tightening in response to a sequence of stagflationary shocks of uncertain magnitude, using a New Keynesian model. Under this type of uncertainty, the monetary policy tightening should be generally milder than in the case of no uncertainty on the shock size, in order to to "perform well" across a number of different possible states of the world, which include the possibility of an elevated inflation persistence or financial amplification. We have not considered the case of uncertainty about the size of an aggregate demand shock or the case of uncertainty about the persistence of a shock. In addition, one may consider an alternative definition of the loss function, featuring output deviations from its *natural* level, as opposed to its steady-state level. We leave these issues for future research.

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Table 1: Steady-state equilibrium

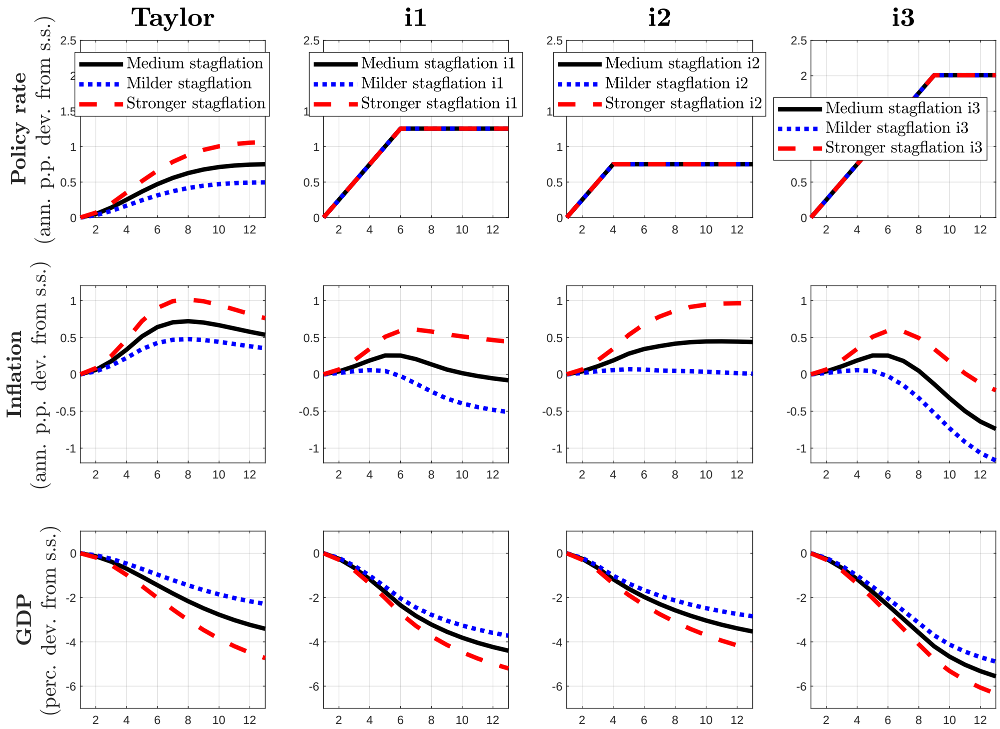
Variable	Value
Inflation rate	2.0
Nominal interest rate	2.0
Real interest rate	0.0
Private consumption	60.0
Public consumption	20.0
Investment	20.0

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

Table 2: Calibration

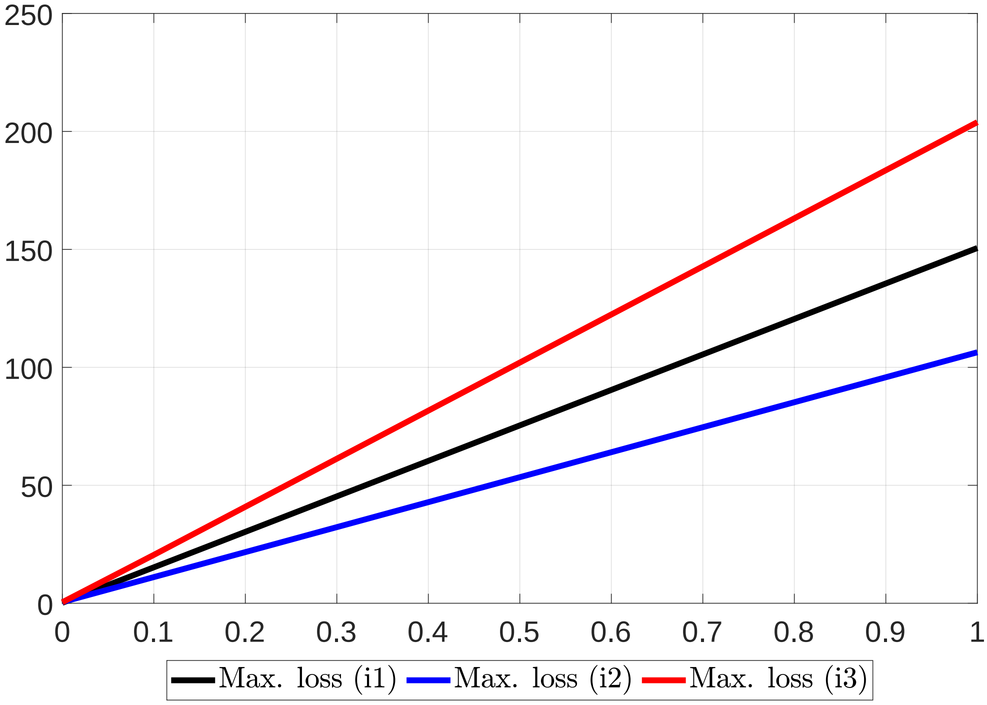
Parameter	Value
Monetary policy	
Interest rate smoothing	0.867
Response to inflation	1.9
Response to output growth	0.15
Preferences	
Elasticity of intertemporal substitution	1
Discount factor	0.99999
Habit in consumption	0.57
Frisch labor elasticity	0.667
Technology	
Share of capital in production	0.24
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)	
Cost push	0.88
Risk premium	0.00
Shock size	
Cost push (medium)	0.0075
Cost push (milder)	0.0050
Cost push (stronger)	0.0105
Risk premium	0.003

Figure 1: Cost-push shock scenarios under the Taylor rule and the alternative target-consistent policy rates.



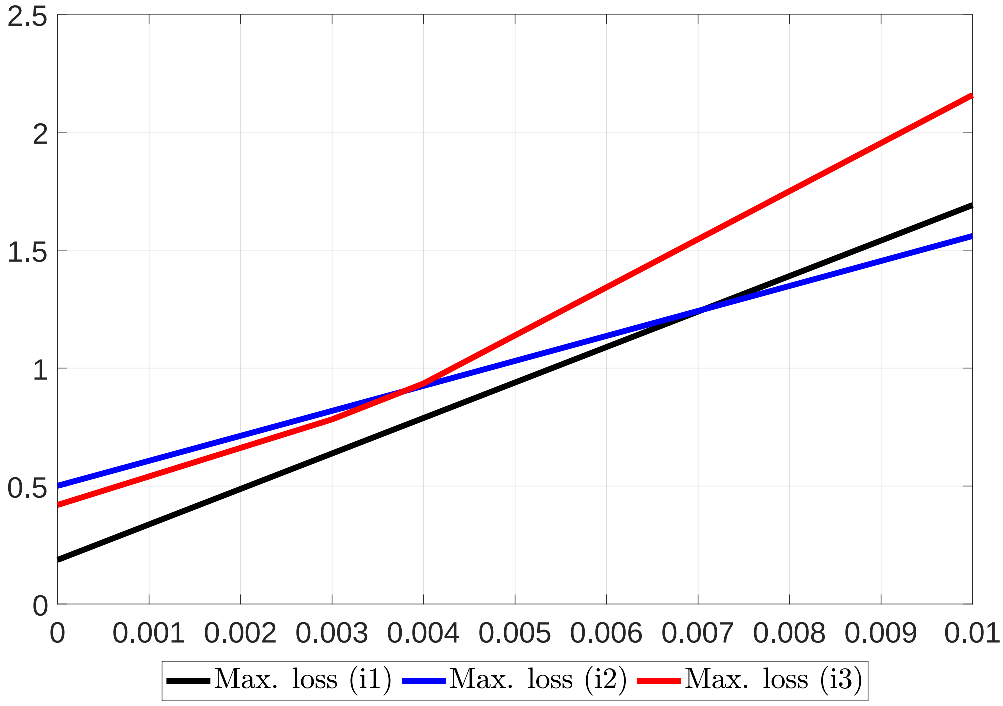
Notes: on the horizontal axis, quarters. i1: target-consistent policy rate under medium stagflation; i2: target-consistent policy rate under milder stagflation; i3: target-consistent policy rate under stronger stagflation. Column "Taylor" reports responses when the calibrated Taylor rule is active under the three cost-push shocks. Column i1 shows responses of policy rate, inflation and output under the three cost-push shocks and the assumption that the central bank implements the policy rate path labelled "i1", i.e., it raises the policy rate to the level consistent with inflation being on target (on average in the third year) under the "medium" sequence of cost-push shocks (black continuous line in the inflation chart). Under the milder and stronger cost-push shock sequences, the same policy rate path i1 induces an undershooting and overshooting of the inflation target, respectively (see blue-dotted and red-dashed lines, respectively). In a similar way, column i2 (i3) shows the responses under the assumption that the central bank implements the policy rate path i2 (i3), which is sufficient to stabilize inflation under the milder (stronger) cost-push shock sequence.

Figure 2: Minimax loss as ω_y varies: minimax approach.



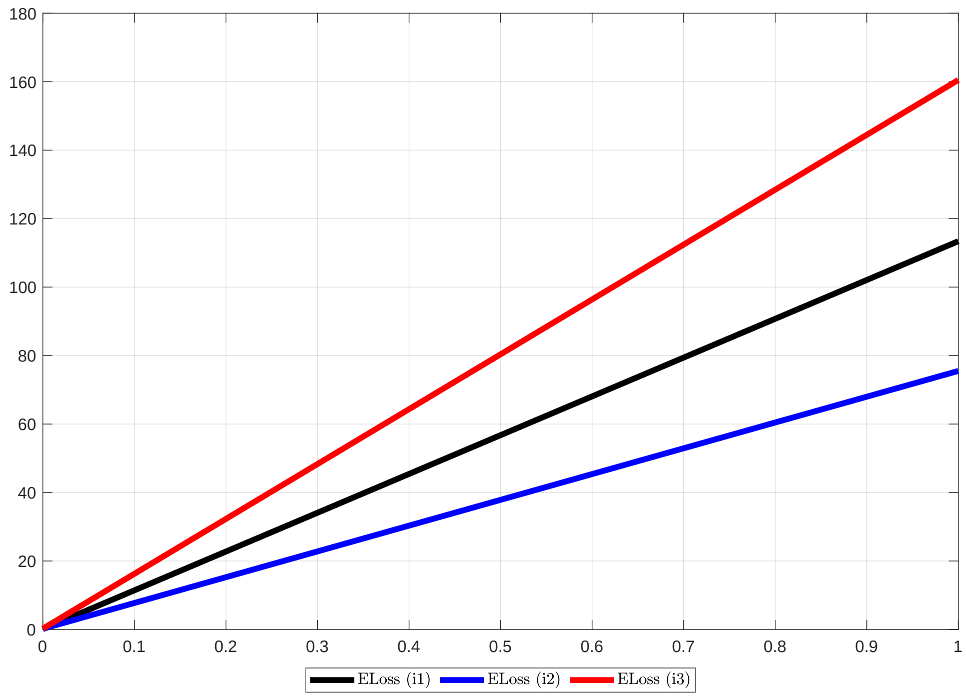
Notes: on the horizontal axis, weight ω_y of output in the loss function; on the vertical axis: largest loss functions under respectively policy rate i1, i2, i3. i1: target-consistent policy rate under medium stagflation; i2: target-consistent policy rate under milder stagflation; i3: target-consistent policy rate under stronger stagflation.

Figure 3: Minimax loss as ω_y varies between 0 and 0.01: minimax approach.



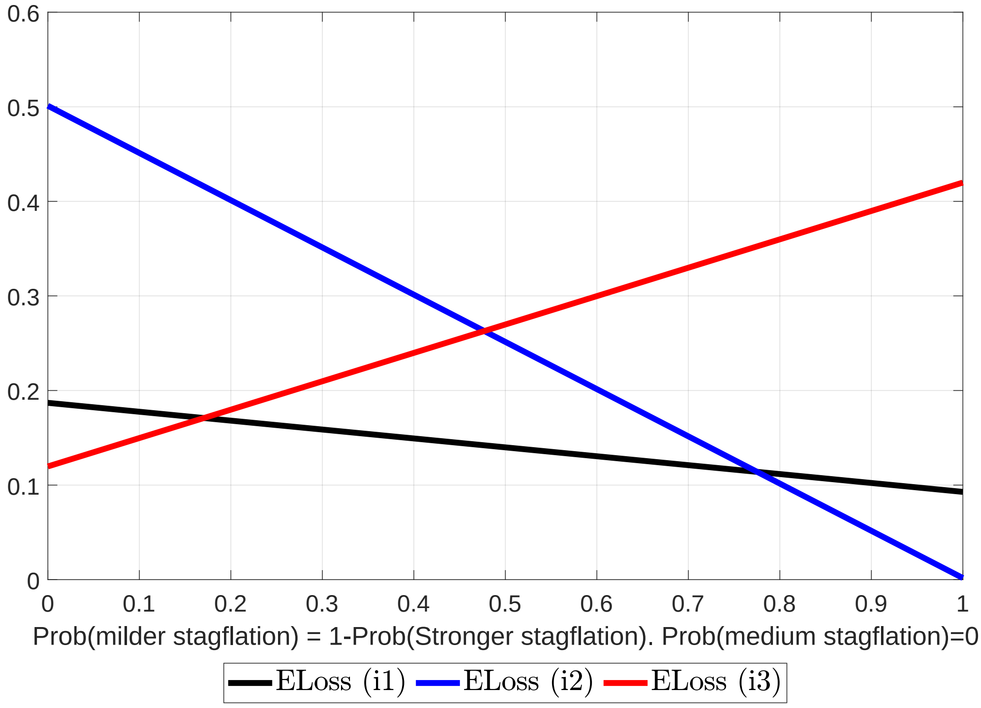
Notes: on the horizontal axis, weight ω_y of output in the loss function; on the vertical axis: largest loss functions under respectively policy rate i1, i2, i3. i1: target-consistent policy rate under medium stagflation; i2: target-consistent policy rate under milder stagflation; i3: target-consistent policy rate under stronger stagflation.

Figure 4: Min-average expected loss as ω_y varies: Bayesian approach.



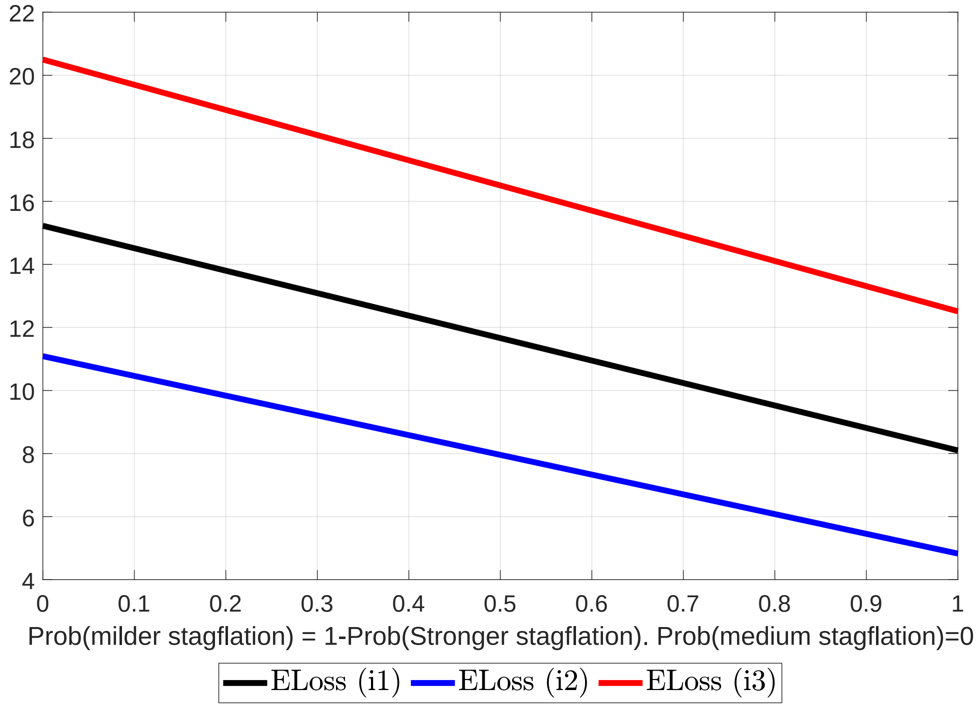
Notes: on the horizontal axis, weight ω_y of output in the loss function. i1: target-consistent policy rate under medium stagflation; i2: target-consistent policy rate under milder stagflation; i3: target-consistent policy rate under stronger stagflation.

Figure 5: Min-average expected loss varying scenarios probabilities, $\omega_y = 0$.



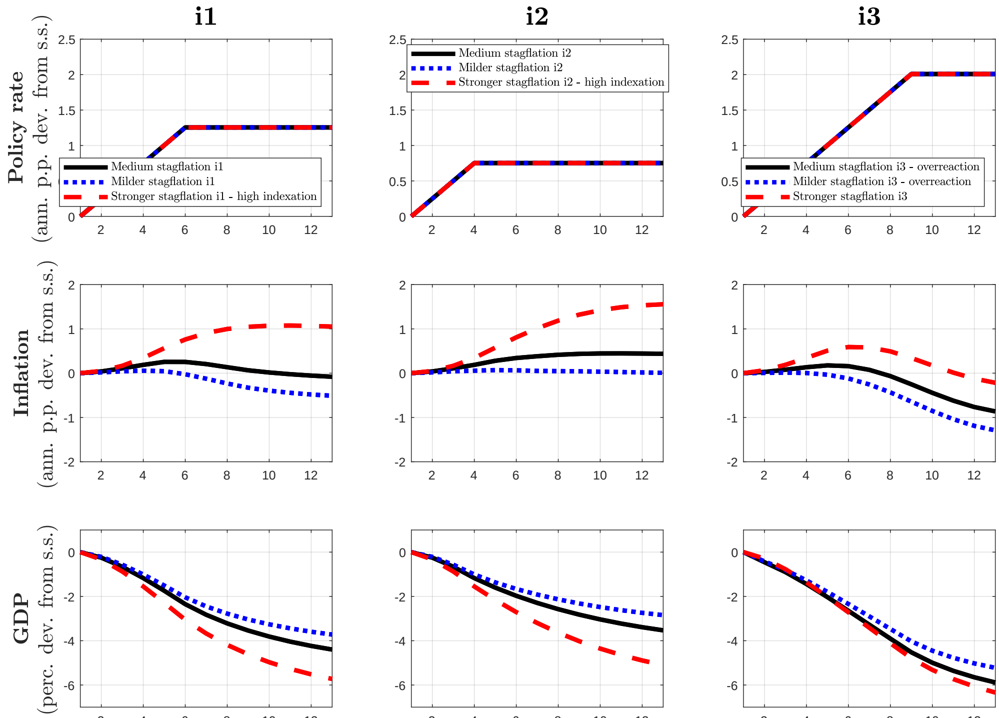
Notes: on the horizontal axis, probability of the milder stagflation scenario (inversely related to the probability of the stronger stagflation scenario, while the probability of the medium stagflation scenario is set to zero). ω_y is the weight of output in the loss function. i1: target-consistent policy rate under medium stagflation; i2: target-consistent policy rate under milder stagflation; i3: target-consistent policy rate under stronger stagflation.

Figure 6: Min-average expected loss varying scenarios probabilities, $\omega_y = 0.1$.



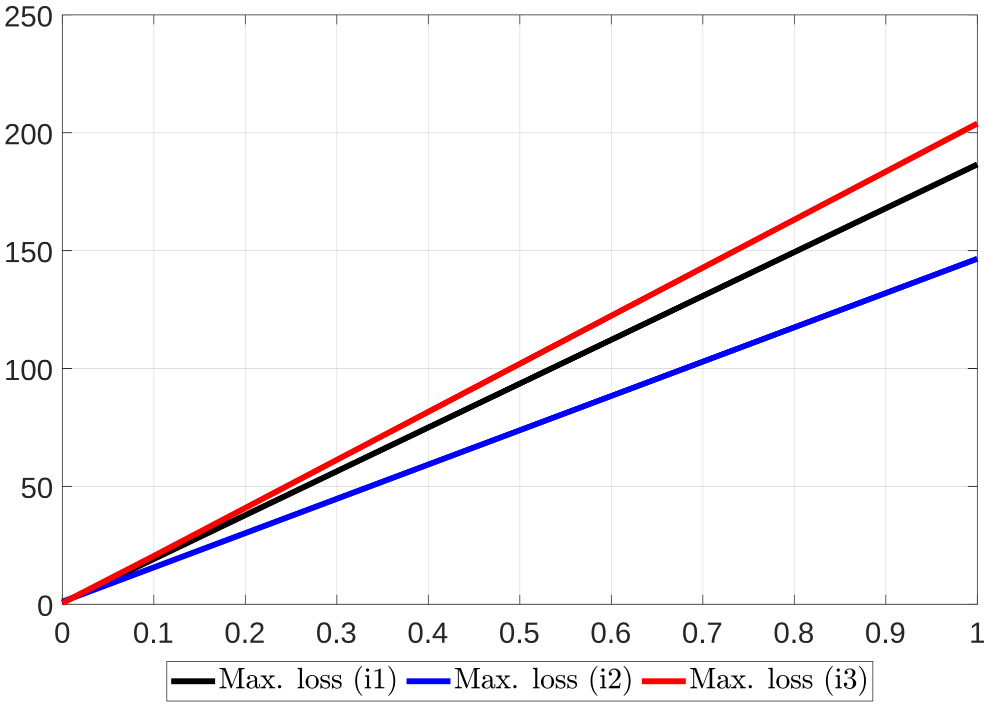
Notes: on the horizontal axis, probability of the milder stagflation scenario (inversely related to the probability of the stronger stagflation scenario, while the probability of the medium stagflation scenario is set to zero). ω_y is the weight of output in the loss function. i1: target-consistent policy rate under medium stagflation; i2: target-consistent policy rate under milder stagflation; i3: target-consistent policy rate under stronger stagflation.

Figure 7: Excessively lax and excessively aggressive monetary policy responses to stagflationary shocks.



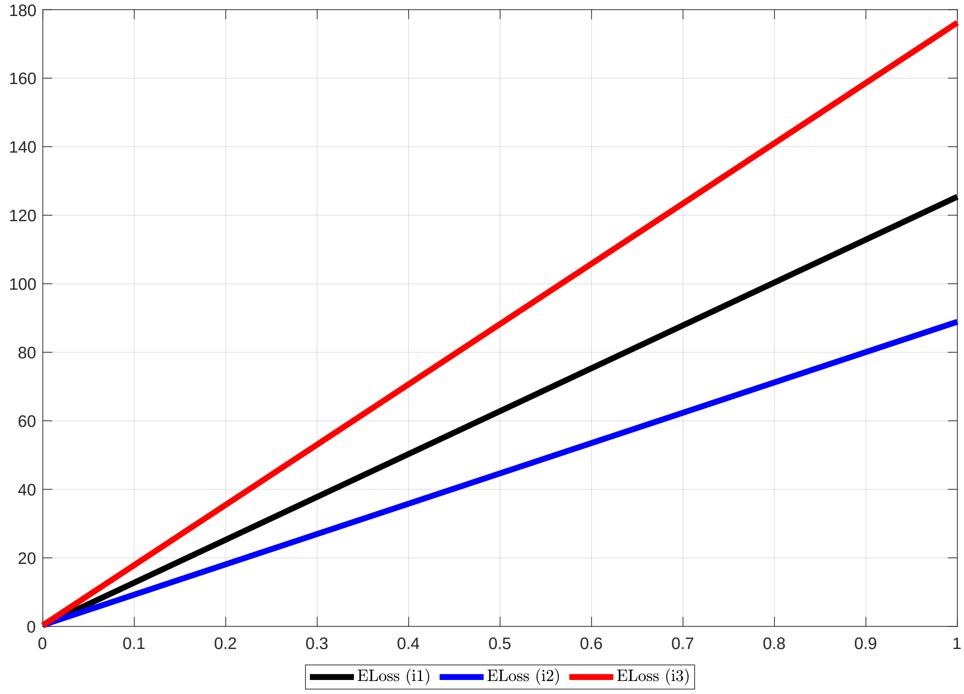
Notes: on the horizontal axis, quarters. i1: target-consistent policy rate under medium stagflation; i2: target-consistent policy rate under milder stagflation; i3: target-consistent policy rate under stronger stagflation. Column i1 shows responses of policy rate, inflation and output under the three cost-push shocks and the assumption that the central bank implements the policy rate path labelled “i1”, i.e., it raises the policy rate to the level consistent with inflation being on target (on average in the third year) under the “medium” sequence of cost-push shocks (black continuous line in the inflation chart). Under the milder and stronger cost-push shock sequences, the same policy rate path i1 induces an undershooting and overshooting of the inflation target, respectively (see blue-dotted and red-dashed lines, respectively). In a similar way, column i2 (i3) shows the responses under the assumption that the central bank implements the policy rate path i2 (i3), which is sufficient to stabilize inflation under the milder (stronger) cost-push shock sequence.

Figure 8: Minimax loss as ω_y varies: Excessively lax and excessively aggressive monetary policy responses to stagflationary shocks.



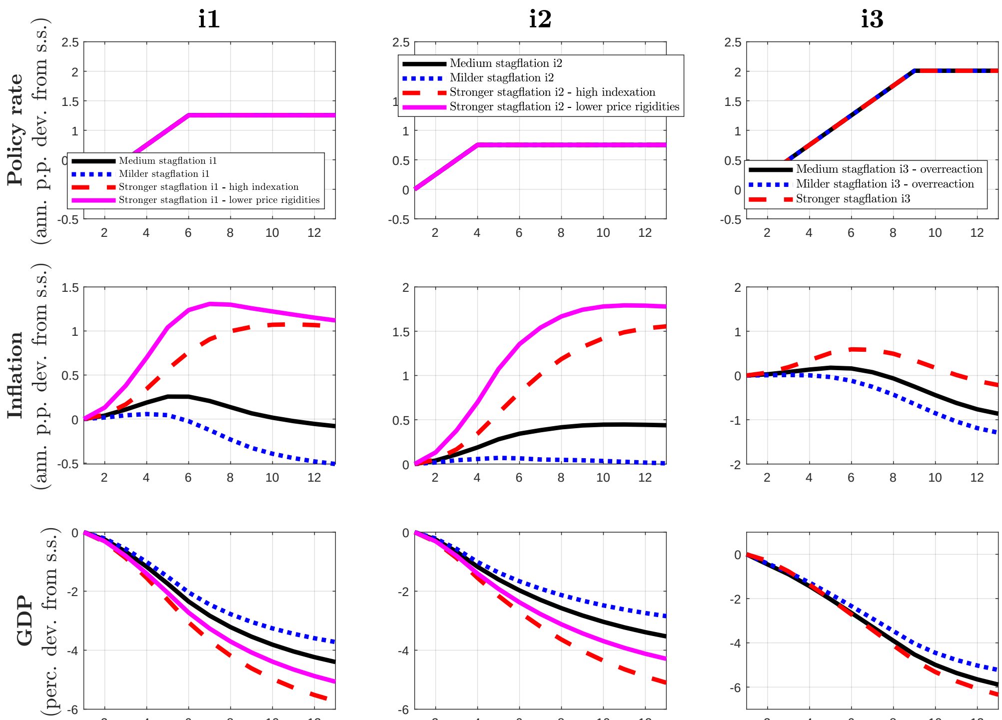
Notes: on the horizontal axis, weight ω_y of output in the loss function; on the vertical axis, largest loss functions under respectively policy rate i1, i2, i3. i1: target-consistent policy rate under medium stagflation; i2: target-consistent policy rate under milder stagflation; i3: target-consistent policy rate under stronger stagflation.

Figure 9: Min-average expected loss as ω_y varies: Excessively lax and excessively aggressive monetary policy responses to stagflationary shocks.



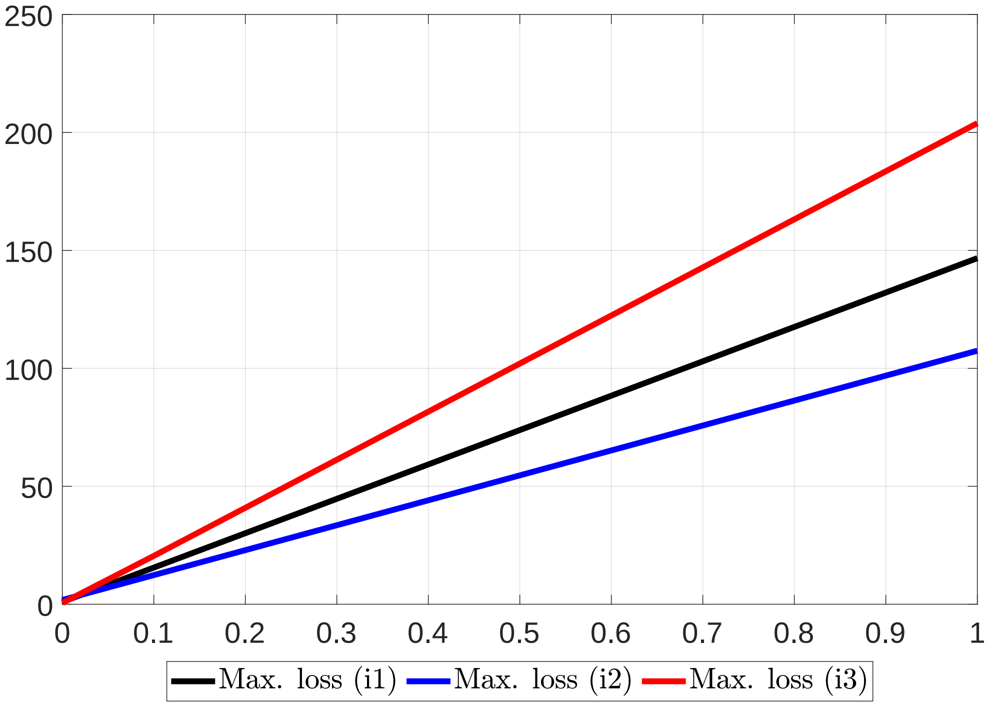
Notes: on the horizontal axis, weight ω_y of output in the loss function; on the vertical axis, largest loss functions under respectively policy rate i1, i2, i3. i1: target-consistent policy rate under medium stagflation; i2: target-consistent policy rate under milder stagflation; i3: target-consistent policy rate under stronger stagflation.

Figure 10: Excessively lax and excessively aggressive monetary policy responses to stagflationary shocks: lower nominal price rigidities.



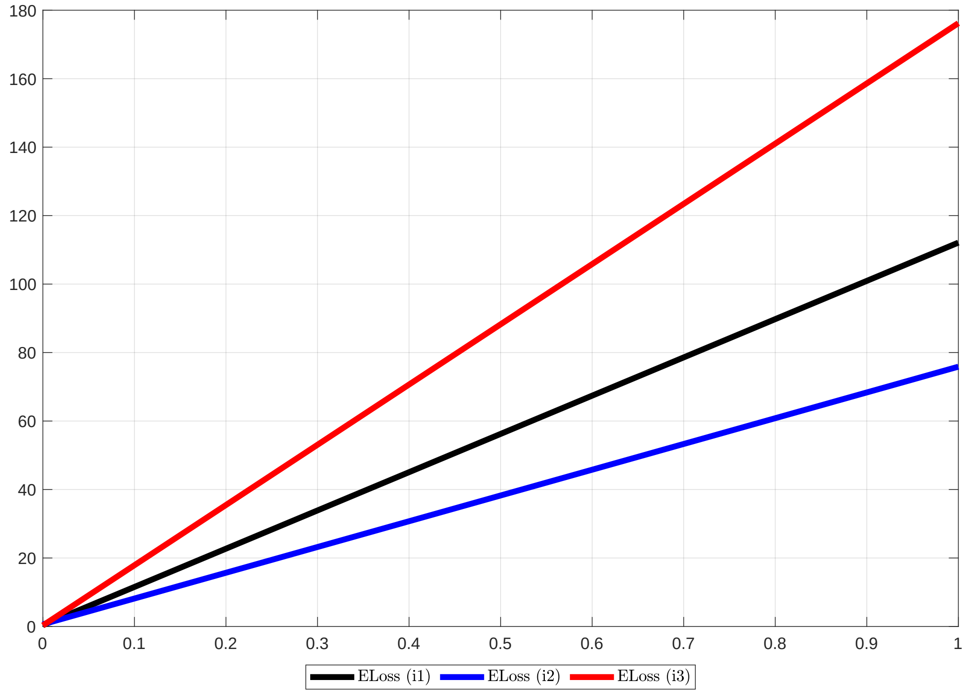
Notes: on the horizontal axis, quarters. i1: target-consistent policy rate under medium stagflation; i2: target-consistent policy rate under milder stagflation; i3: target-consistent policy rate under stronger stagflation. Column i1 shows responses of policy rate, inflation and output under the three cost-push shocks and the assumption that the central bank implements the policy rate path labelled "i1", i.e., it raises the policy rate to the level consistent with inflation being on target (on average in the third year) under the "medium" sequence of cost-push shocks (black continuous line in the inflation chart). Under the milder and stronger cost-push shock sequences, the same policy rate path i1 induces an undershooting and overshooting of the inflation target, respectively (see blue-dotted and red-dashed lines, respectively). In a similar way, column i2 (i3) shows the responses under the assumption that the central bank implements the policy rate path i2 (i3), which is sufficient to stabilize inflation under the milder (stronger) cost-push shock sequence.

Figure 11: Minimax loss as ω_y varies: lower nominal price rigidities.



Notes: on the horizontal axis, weight ω_y of output in the loss function; on the vertical axis, largest loss functions under respectively policy rate i1, i2, i3. i1: target-consistent policy rate under medium stagflation; i2: target-consistent policy rate under milder stagflation; i3: target-consistent policy rate under stronger stagflation.

Figure 12: Min-average expected loss as ω_y varies: lower nominal price rigidities.



Notes: on the horizontal axis, weight ω_y of output in the loss function; on the vertical axis, largest loss functions under respectively policy rate i1, i2, i3. i1: target-consistent policy rate under medium stagflation; i2: target-consistent policy rate under milder stagflation; i3: target-consistent policy rate under stronger stagflation.

Appendix

A Model equations

Final goods production sector: generic firm z

- Production of the generic final good z

$$Y_{z,t} = \left(\int_0^1 Y_{i,t}^{\frac{\theta-1}{\theta}} \, di \right)^{\frac{\theta}{\theta-1}} \tag{A.1}$$

Each firm z maximizes profits with respect to each intermediate good i subject to the above technology constraint and taking prices as given (perfect competition regime). The implied demand and marginal production cost functions are reported in what follows.

- Demand for intermediate good i

$$Y_{z,i,t} = \left(\frac{P_{i,t}}{P_t} \right)^{-\theta} Y_{z,t} \tag{A.2}$$

- Price deflator (marginal production cost)

$$P_{z,t} = \left(\int_0^1 P_{i,t}^{1-\theta} \, di \right)^{\frac{1}{1-\theta}} \tag{A.3}$$

- Aggregate production

$$Y_t = \int_0^1 Y_{z,t} \, dz \tag{A.4}$$

Intermediate production sector: generic firm i

- Production function

$$Y_{i,t} = K_{i,t-1}^{\alpha} L_{i,t}^{1-\alpha}, \tag{A.5}$$

Each firm i minimizes production costs with respect to capital and labor subject to the above technology constraint and taking prices as given. The implied demand curves for capital and labor are reported in in what follows.

- FOC with respect to capital $K_{i,t}$

$$K_{i,t} = \alpha \left(\frac{r_{k,t}}{rmc_t} \right)^{-1} Y_{i,t} \tag{A.6}$$

where $r_{k,t}$ is the return on capital.

- FOC with respect to labor $L_{i,t}$

$$L_{i,t} = (1-\alpha) \left(\frac{w_t}{rmc_t} \right)^{-1} Y_{i,t} \tag{A.7}$$

where

$$L_{i,t} = \left(\int_0^1 L_{j,t}^{\frac{\theta_w - 1}{\theta_w}} \, dj \right)^{\frac{\theta_w}{\theta_w - 1}} \tag{A.8}$$

- FOC with respect to labor $L_{j,t}$

$$L_{j,t} = \left(\frac{w_{j,t}}{w_t} \right)^{-\theta_w} L_{i,t} \tag{A.9}$$

$$w_t \equiv \frac{W_t}{P_t} \tag{A.10}$$

$$w_{j,t} \equiv \frac{W_{j,t}}{P_t} \tag{A.11}$$

$$W_t = \left(\int_0^1 W_{j,t}^{1-\theta_w} \, dj \right)^{\frac{1}{1-\theta_w}} \tag{A.12}$$

Given the marginal cost, each firm i maximizes, under a monopolistic competition regime, its profits with respect to the price of its product i subject to the demand for its good from firms in the final sector and to the following quadratic adjustment cost on prices

$$\frac{\kappa_P}{2}\left(\frac{P_{i,t}/P_{i,t-1}}{\pi_{t-1}^{ind_p}\pi_{target}^{1-ind_p}}-1\right)^2 Y_t \tag{A.13}$$

where κ_P is a parameter measuring the adjustment cost, π_t is the period-on-period inflation rate, π_{target} is the central bank inflation target, and ind_p measures the degree of price indexation to past inflation, while $(1-ind_p)$ measures indexation to the inflation target. The implied supply curve of the product i is reported in what follows.

- FOC with respect to nominal price $P_{i,t}$

$$\theta\frac{MC_t}{P_t}\frac{1}{Y_t}+(1-\theta)\frac{P_{i,t}^{1-\theta}}{P_t^{-\theta}}\frac{1}{Y_t}=\lambda_{j,t}\kappa_P\left(\frac{P_{i,t}/P_{i,t-1}}{\pi_{t-1}^{ind_p}\pi_{target}^{1-ind_p}}-1\right)\frac{P_{i,t}/P_{i,t-1}}{\pi_{t-1}^{ind_p}\pi_{target}^{1-ind_p}}$$
$$-\beta\lambda_{j,t+1}\kappa_P\left(\frac{P_{i,t+1}/P_{i,t}}{\pi_{t}^{ind_p}\pi_{target}^{1-ind_p}}-1\right)\frac{P_{i,t+1}P_{t+1}/P_{i,t}^2Y_{t+1}}{\pi_{t}^{ind_p}\pi_{target}^{1-ind_p}Y_t} \tag{A.14}$$

Generic household j

- Utility function

$$E_0\left\{\sum_{s=0}^{\infty}\beta^s\left[log\left(C_{j,s}-b_cC_{s-1}\right)-\frac{1}{1+\zeta}L_{j,s}^{1+\zeta}\right]\right\} \tag{A.15}$$

where we assume external consumption habit ($0<b_c<1$) and that the economy is cashless. The utility is separable in consumption and labor supply.

- Budget constraint

$$B_{j,s}\left(\varepsilon_s^bR_s\right)^{-1}-B_{j,s-1}=\Pi_s+W_{j,s}L_{j,s}+r_s^KK_{j,s-1}-I_{j,s}-C_{j,s}-Tax_{j,s}-\frac{\kappa_W}{2}\left(\frac{W_{j,s,t}/W_{j,s,t-1}}{\pi_{s-1}^{ind_w}\pi_{target}^{1-ind_w}}-1\right)^2W_sL_s \tag{A.16}$$

where B is a riskless bond, paying the monetary policy rate R, exchanged among households and in zero net supply (ε_t^b is a risk premium shock following an AR(1) process), $W_{j,s}$ is the nominal wage set by the household (that supplies labor under monopolistic competition), r^K is the return on physical capital, Π represent profits from firms' ownership (rebated to households in a lump-sum way), $Tax_{j,s}$ are lump-sum taxes. The last term on the right-hand side represents quadratic adjustment costs paid by households when setting the nominal wage, where κ_W is a parameter measuring nominal rigidities, π_t is the period-on-period inflation rate, π_{target} is the central bank inflation target, ind_w measures the degree of wage indexation to past inflation, while $(1 - ind_w)$ measures indexation to the inflation target, and

$$L_t = \int_0^1 L_{i,t}\, di \tag{A.17}$$

is the total labor demand by firms in the intermediate sector.

- Capital accumulation law

$$K_{j,t} = (1-\delta)K_{j,t-1} + \left[1 - \frac{\psi}{2}\left(\frac{I_{j,t}}{I_{j,t-1}} - 1\right)^2\right] I_{j,t} \tag{A.18}$$

where $0 < \delta < 1$ is the depreciation rate and the level of investment is subject to a quadratic adjustment cost and $\psi > 0$ is a parameter measuring the cost of adjustment.

- FOC with respect to consumption $C_{j,t}$

$$\lambda_{j,t} = (C_{j,t} - b_c C_{t-1})^{-1} \tag{A.19}$$

- FOC with respect bond $B_{j,t}$

$$\lambda_{j,t} = \beta E_t \lambda_{j,t+1} R_t \varepsilon_t^b \pi_{t+1}^{-1} \tag{A.20}$$

- FOC with respect to the end-of-period capital $K_{j,t}$

$$\lambda_{j,t} Q_{j,t} = E_t \left[\beta \lambda_{j,t} r_{t+1}^K + (1-\delta)\lambda_{j,t} Q_{j,t+1}\right] \tag{A.21}$$

where Q is the Tobin's Q (i.e., the multiplier of the capital accumulation law),

- FOC with respect to investment $I_{j,t}$

$$\lambda_{j,t} = Q_{j,t}\lambda_{j,t}\left[1 - \frac{\psi}{2}\left(\frac{I_{j,t}}{I_{,jt-1}} - 1\right)^2 - \psi\left(\frac{I_{j,t}}{I_{j,t-1}} - 1\right)\frac{I_{j,t}}{I_{j,t-1}}\right]$$
$$+\lambda_{,jt+1}\psi\left[\left(\frac{I_{j,t+1}}{I_{j,t}} - 1\right)\frac{I^2_{j,t+1}}{I^2_{j,t}}\right] \tag{A.22}$$

- FOC with respect to nominal wage $W_{j,t}$

$$\theta_L \frac{W_{j.t}^{-\theta_L(1+\zeta)-1}}{W_t^{-\theta_L(1+\zeta)}}\frac{L^{\zeta}_{j,t}}{L_t} + (1-\theta_L)\frac{\lambda_{j,t}}{L_t}\frac{W_{j,t}^{-\theta_L}}{W_t^{-\theta_L}} = \lambda_{j,t}\kappa_W\left(\frac{W_{j,t}/W_{j,t-1}}{\pi^{ind_w}_{W,t-1}\pi^{1-ind_w}_{target}} - 1\right)\frac{W_t L_t/W_{j,t-1}}{\pi^{ind_w}_{W,t-1}\pi^{1-ind_w}_{target}}$$
$$-\beta\lambda_{j,t+1}\kappa_W\left(\frac{W_{j,t+1}/W_{j,t}}{\pi^{ind_w}_{W,t}\pi^{1-ind_w}_{target}} - 1\right)\frac{W_{j,t+1}W_{t+1}/W^2_{j,t}L_{t+1}}{\pi^{ind_w}_{W,t}\pi^{1-ind_w}_{target}L_t} \tag{A.23}$$

Monetary policy

$$\frac{R_t}{\overline{R}} = \left(\frac{R_{t-1}}{\overline{R}}\right)^{\rho_r}\left(\frac{\pi_t}{\overline{\pi}}\right)^{(1-\rho_r)\rho_\pi}\left(\frac{y_t}{y_{t-1}}\right)^{(1-\rho_r)\rho_y} \tag{A.24}$$

Fiscal policy

- Government budget constraint

  In every period public purchases are financed by lump-sum taxes on households

$$G_t = \int_0^1 Tax_{j,t}\,dj \tag{A.25}$$

- Constant (steady-state) public purchases

$$G_t = \bar{G} \tag{A.26}$$

Market clearing conditions

- Generic intermediate good i

$$Y_{i,t} = \int_0^1 Y_{z,i,t}\, dz \tag{A.27}$$

- Final good

$$Y_t = \int_0^1 C_{j,t}\, dj + \int_0^1 I_{j,t}\, dj + G_t + \frac{\kappa_P}{2} \int_0^1 \left(\frac{P_{i,t}/P_{i,t-1}}{\pi_{t-1}^{ind_p} \pi_{target}^{1-ind_p}} - 1 \right)^2 Y_t\, di$$
$$+ \frac{\kappa_W}{2} \int_0^1 \left(\frac{W_{j,t}/W_{j,t-1}}{\pi_{t-1}^{ind_w} \pi_{target}^{1-ind_w}} - 1 \right)^2 \frac{W_t}{P_t} L_t\, dj \tag{A.28}$$

- Bonds

$$\int_0^1 B_{j,t}\, dj = 0 \tag{A.29}$$

- Physical capital

$$\int_0^1 K_{j,t}\, dj = \int_0^1 K_{i,t}\, di \tag{A.30}$$

- Generic labor j

$$L_{j,t} = \int_0^1 L_{i,j,t}\, di \tag{A.31}$$

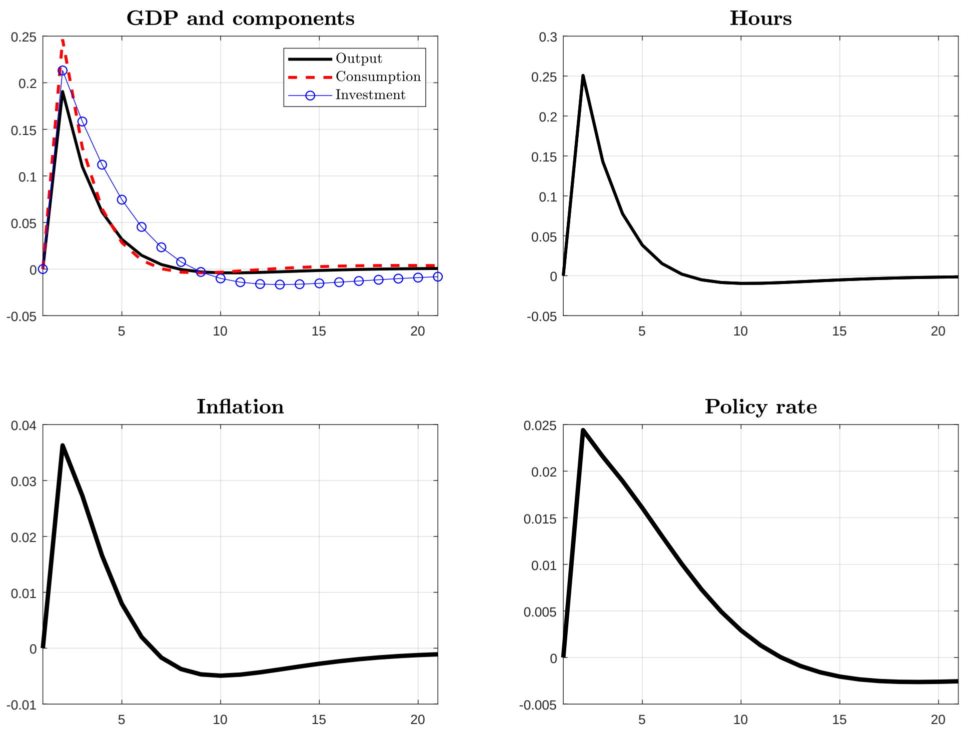
Definition of equilibrium

We consider a symmetric equilibrium where (i) both the representative firm in the final production sector and the representative firm in the intermediate production sector maximize their corresponding profits subject to their (technology and demand) constraints, (ii) the representative household maximizes her intertemporal utility function subject to the budget constraint and labor demand, (iii) the central bank follows the Taylor rule, (iv) the government budget constraint holds, and (v) all markets clear.

B Risk premium shock

In Section 4.3 we introduce an exogenous risk-premium shock linked to an excessive monetary policy restriction under i3 in the case of milder or medium stagflations. In this Section, we show that the propagation of this risk premium shock under a systematic Taylor rule is in line with Smets and Wouters (2007). Indeed, Figure B1 reports the responses of main macroeconomic variables to an expansionary risk premium shock, i.e. a temporary decrease in the short-term rate paid on private bonds. The persistence and standard deviation of the shock are the same as those calibrated in Section 4.3 with the only difference that here we show a temporary decrease rather than increase in the risk premium, to facilitate the comparison with the corresponding figure reported in Smets and Wouters (2007). The shock causes an expansion in aggregate demand and hence in output and inflation. As a consequence, the Taylor rule commands an increase in the policy rate. All in all, the dynamics are akin to those reported in Smets and Wouters (2007).

Figure B1: Impulse responses to a risk premium shock.



Notes: on the horizontal axis, quarters. Output, consumption, investment and hours are in percent deviations from the steady state. Inflation and policy rate are in annualized percentage points deviations from steady state. “Hours” is for hours worked.

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