WORKING paper

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# When Do Persistent Supply Shocks Call for Hawkishness?[1]

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## ABSTRACT

Central banks typically rely on the following heuristic: Look through transitory supply shocks to stabilize the output gap, but pivot toward inflation stabilization when supply shocks become persistent. Yet standard macroeconomic models provide little support for this heuristic. They justify it for markup shocks—a particular type of supply disturbance—but imply that, for the most common supply shocks, such as productivity, labor supply, or energy prices, stabilizing the output gap remains close to optimal even when these shocks are persistent. What, then, rationalizes a hawkish response to persistent supply shocks? This paper shows that, contrary to conventional wisdom, the risk that inflation expectations de-anchor is not sufficient. Even when expectations are backward-looking, output-gap stabilization remains close to optimal. Instead, real wage rigidity emerges as the key mechanism. When real wages are sufficiently rigid, stabilizing the output gap becomes substantially more costly, and optimal policy shifts toward inflation stabilization in response to persistent supply shocks, regardless of whether expectations can de-anchor. These findings suggest that monitoring real wage rigidity may be at least as important as monitoring inflation expectations when assessing the need for a hawkish policy pivot.

Keywords: Supply Shocks ; De-Anchoring ; Real Wage Rigidity.

JEL classification: E52, E31, E58



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# NON-TECHNICAL SUMMARY

In the face of supply shocks, central banks typically rely on the following heuristic. If the shock is transitory, policymakers should react moderately and prioritize output-gap stabilization. If it is persistent, however, policy should place greater weight on inflation stabilization because of concerns that inflation expectations may de-anchor. This heuristic structured much of the debate on the monetary policy response to the inflation surge of 2021-2023. The recent sharp increase in global energy prices following the blockade of the Strait of Hormuz has brought this heuristic back to the forefront of monetary policy debates.

Yet standard monetary models provide little support for the idea that monetary policy should tilt toward stabilizing inflation when supply shocks are persistent. For the main types of supply shocks that central banks face in practice—productivity shocks such as supply chain disruptions, labor supply shocks such as changes in participation and sectoral reallocation, oil/gas price shocks and other relative-price shocks—standard models find that stabilizing the output gap (the deviation of output from its efficient level) is very close to optimal, even when these shocks are persistent. This is illustrated on the left panel of the figure: under rational expectations, dovish policies that are close to stabilizing the output gap generate a much lower loss than hawkish policies that are close to stabilize inflation.

Does this mean that central banks' supply shock heuristic is wrong, or that standard models miss important aspects of reality? This paper shows that the heuristic can indeed be rationalized. Contrary to conventional wisdom, however, the key mechanism is not the risk of de-anchoring inflation expectations, but sufficiently strong real wage rigidity. This suggests that monitoring the extent of real wage rigidity is at least as important as monitoring inflation expectations to assess the need for a hawkish pivot.

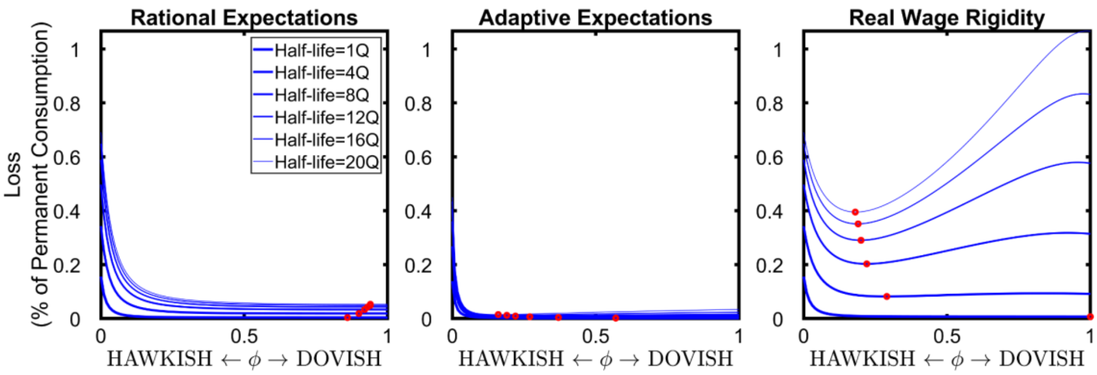
The paper's first main result is that de-anchoring risks do not significantly alter the optimal policy recommendations of the standard model. In response to productivity, labor supply, and energy price shocks, stabilizing the output gap remains very close to optimal, regardless of the persistence of the shocks (see middle panel of the figure).

The reason output-gap stabilization remains nearly optimal is ultimately the same as in the standard model with fully anchored expectations. When there are both price and wage rigidities, monetary policy does not have much impact on the real wage. What it does affect is whether a decrease in the real wage occurs through price increases or wage decreases, or any combination of the two. But stabilizing the output gap turns out to deliver a very good split between price increases and wage decreases, which minimizes the costs of price and wage inflation, all while avoiding fluctuations in the output gap. De-anchoring risks do not challenge this logic.

The paper's second main result is that while de-anchoring risks per se do not rationalize a hawkish pivot when supply shocks are persistent, something else does: a sufficient degree of real wage rigidity. Real wage rigidity can be interpreted as capturing explicit or implicit cost-of-living adjustments (COLA) whereby nominal wages catch up with prices when inflation would otherwise erode real wages. I show that if real wage rigidity is sufficiently high, stabilizing the output gap against persistent non-markup shocks becomes very costly (see right panel of figure). As a result, the optimal policy shifts from stabilizing the output gap when the shock is transitory to stabilizing price inflation more when the shock is persistent. This rationalizes central banks' supply shock heuristic, but applies even if inflation expectations are rational and cannot de-anchor.

What real wage rigidity changes is that stabilizing the output gap no longer splits a decrease in the real wage between price increases and wage decreases. Instead, when real wages are sufficiently rigid, prices and wages move in the same direction. This generates substantial inflation in both prices and wages. To limit these distortions, monetary policy becomes willing to tolerate a negative output gap. The incentive to do so increases with supply shock persistence, because the inflation-wage comovement becomes more prolonged.

**Figure: Central Bank Loss under Different Assumptions**




*Note:* The figure reports the welfare losses associated with monetary-policy rules that place greater weight on inflation stabilization (hawkish, left) or output-gap stabilization (dovish, right) in response to energy-price shocks with different half-lives. The first panel shows that, in the standard model with rational expectations, a dovish policy that stabilizes the output gap remains close to optimal even when shocks are highly persistent. The second panel shows that this result continues to hold when expectations are adaptive and can become de-anchored. The third panel shows that, in the presence of sufficiently strong real wage rigidity, output-gap stabilization becomes substantially more costly as shock persistence increases.

# Quand un choc d'offre persistant justifie-t-il une politique monétaire plus agressive ?

## RÉSUMÉ


Les banques centrales s'appuient généralement sur l'heuristique suivante : accommoder les chocs d'offre transitoires afin de stabiliser l'écart de production, mais répondre agressivement pour stabiliser l'inflation lorsque les chocs sont persistants. Pourtant, les modèles standards apportent peu de soutien à cette heuristique. Ils la justifient dans le cas des chocs de taux de marge — un type particulier de choc d'offre — mais concluent que, pour les chocs d'offre auxquels les banques centrales sont confrontées en pratique — chocs de productivité, d'offre de travail, ou de prix de l'énergie —, stabiliser l'écart de production demeure proche de l'optimum, même lorsque les chocs sont persistants. Qu'est-ce qui peut alors justifier l'heuristique des banques centrales ? Cet article montre que, contrairement à une idée largement répandue, le risque de désancrage des anticipations est insuffisant. Même lorsque les anticipations sont adaptatives et peuvent se désancrer, la stabilisation de l'écart de production reste proche de l'optimum. En revanche, la rigidité des salaires réels fournit une justification à une réponse monétaire plus agressive. Lorsque les salaires réels sont suffisamment rigides, stabiliser l'écart de production devient beaucoup plus coûteux et la politique monétaire optimale accorde un poids croissant à la stabilisation de l'inflation à mesure que la persistance des chocs augmente, que les anticipations puissent ou non se désancrer. Ces résultats suggèrent que, pour évaluer la nécessité d'un resserrement monétaire face à un choc d'offre persistant, le suivi de la rigidité des salaires réels est au moins aussi important que celui des anticipations d'inflation.



Mots-clés : chocs d'offre ; désancrage ; rigidité des salaires réels ; politique monétaire.

# Introduction

Powell (2024) calls it *"standard thinking"* and Lagarde (2021) *"what monetary policy should normally [do]"*: In the face of supply shocks, central banks typically rely on the following heuristic.[1] If the supply shock is transitory, react moderately and prioritize stabilizing the output gap, even if it implies letting inflation rise temporarily above target. But if the supply shock is persistent, shift the focus to stabilizing inflation, as the risk of de-anchoring inflation expectations looms. This heuristic structured much of the debate on the monetary policy response to the inflation surge of 2021-2023: those defending central banks' initial response emphasized the transitory nature of the shock, while proponents of a more hawkish response argued that it was persistent. The recent sharp increase in global energy prices following the blockade of the Strait of Hormuz has brought this heuristic back to the forefront of monetary policy debates.

Yet standard monetary models provide little support for the idea that monetary policy should tilt toward stabilizing inflation when supply shocks are persistent. In standard models, optimal monetary policy tilts toward stabilizing inflation only for persistent *markup* shocks—a particular type of supply shock. For the main types of supply shocks that central banks face in practice—productivity shocks such as supply chain disruptions, labor supply shocks such as changes in participation and sectoral reallocation, oil/gas price shocks and other relative-price shocks—stabilizing the output gap is very close to optimal, however persistent the shock is. This is obviously the case when stabilizing the output gap also stabilizes inflation (the divine coincidence, Blanchard and Galí 2007). But it continues to be the case when stabilizing the output gap means letting price inflation depart from target, either because both prices and nominal wages are sticky (Erceg, Henderson, and Levin 2000, Bodenstein, Erceg, and Guerrieri 2008) or because prices are sticky in two or more sectors (La'O and Tahbaz-Salehi 2022, Rubbo 2023).

[1] Powell (2024): *"Standard thinking has long been that, as long as inflation expectations remain well anchored, it can be appropriate for central banks to look through a temporary rise in inflation. [. . . ] Beginning in October, the data turned hard against the transitory hypothesis. [. . . ] We recognized that and pivoted beginning in November."* Lagarde (2021): *"Monetary policy should normally "look through" temporary supply-driven inflation, so long as inflation expectations remain anchored."* See also e.g. Lagarde (2025) for a statement after the inflation surge: *"Classically, monetary policy [. . . ] "looks through" or reacts less to supply shocks that push output and inflation in opposite directions if they are sufficiently small and transitory."*

Does this mean that central banks' supply shock heuristic is wrong, or that standard models miss important aspects of reality? If so, what features of reality, which are missing in standard models, rationalize the heuristic? This paper shows that central banks' supply shock heuristic can be rationalized, but that, contrary to conventional wisdom, de-anchoring risks are neither sufficient nor necessary. Instead, the main feature that can rationalize a hawkish pivot for persistent supply shocks is the existence of sufficiently strong real wage rigidity. This suggests that monitoring the extent of real wage rigidity is at least as important as monitoring inflation expectations to assess the need for a hawkish pivot.

To make this point, the paper intentionally uses as its backbone the most conventional set-up: a standard New-Keynesian environment with both price and nominal wage rigidities (Erceg, Henderson, and Levin 2000).[2] It considers five types of supply shocks: price markup shocks, wage markup shocks, productivity shocks, labor supply shocks, and energy price shocks. As mentioned above, in the baseline version of the model the supply shock heuristic only applies to markup shocks. Against the non-markup shocks—productivity, labor supply, energy prices—stabilizing the output gap is very close to optimal, however persistent the shocks are. Stabilizing the output gap is even exactly optimal for a particular (but not extreme) set of calibrations. Since the supply shocks central banks worry about in practice are non-markup shocks, this fails to rationalize the central bank heuristic.[3]

The conclusion of the standard model may not be overly surprising though. The main argument to justify a hawkish pivot when shocks are persistent is the risk of de-anchoring inflation expectations. Yet, the standard model abstracts from de-anchoring risks by assuming rational expectations. The paper, therefore, first reconsiders the model assuming that expectations are backward-looking, following Preston (2005)'s approach, instead of rational,

[2]With a single sector and price or nominal wage rigidity alone, the divine coincidence obtains, so the question of stabilizing inflation or the output gap is moot. It takes two nominal rigidities to make a real one and to create a monetary policy trade-off.

[3]It would if markup shocks were the main type of supply shocks. An argument in favor of the importance of markup shocks is that standard midscale DSGE models such as Smets and Wouters (2007) find them to explain the largest shares of inflation variance (see also Fratto and Uhlig 2020). Yet, Smets and Wouters's model does not include energy price shocks, nor other inputs whose supply can run into bottlenecks and create large relative price shocks. The importance of such relative price shocks is one message of the recent literature on production networks in monetary economies (e.g. La'O and Tahbaz-Salehi 2022, Rubbo 2023). Blanchard and Galí (2009) find using a VAR that oil price shocks account for around 50% of the standard deviation of CPI inflation in both the 1970s and the 2000s.

so that they can de-anchor.

The paper's first main result is that de-anchoring risks do not significantly alter the optimal policy recommendations of the model. In response to productivity, labor supply, and energy price shocks, stabilizing the output gap remains very close to optimal, regardless of the persistence of the shocks. Once again, stabilizing the output gap is even exactly optimal for a particular set of calibrations, although a somewhat narrower set than in the case of rational expectations. Optimal policy does recommend a shift to stabilizing inflation in response to persistent markup shocks, but this is already the case under rational expectations.

The reason why stabilizing the output gap still works well is ultimately the same as under rational expectations. When there are both price and wage rigidities, monetary policy does not have much impact on the real wage. What it does affect is whether a decrease in the real wage occurs through price increases or wage decreases, or any combination of the two. But stabilizing the output gap turns out to deliver a very good split between price increases and wage decreases, which minimizes the costs of price and wage inflation, all while avoiding fluctuations in the output gap. De-anchoring risks do not challenge this logic. Under the optimal policy, the output gap is very close to zero and long-term inflation expectations depart from target for some time, but then converge back to target.

The paper's second main result is that while de-anchoring risks per se do not rationalize a hawkish pivot when supply shocks are persistent, something else does: a sufficient degree of real wage rigidity. I introduce real wage rigidity in a way that is both a natural counterpart to nominal wage rigidity and allows for analytical tractability. Unions set *real* wages under staggered Calvo wage-setting. During the spell of a real wage, nominal wages are automatically indexed to price inflation so that the real wage remains constant. Real wage rigidity can therefore be interpreted as capturing explicit or implicit cost-of-living adjustments in wages (COLA) whereby nominal wages catch up with prices when inflation would otherwise erode real wages. Like under Calvo nominal wage rigidity, real wages are not perfectly rigid and respond to shocks, in a forward-looking manner (under rational expectations at least).

I show that if real wage rigidity is sufficiently high, stabilizing the output gap against persistent non-markup shocks becomes very costly. As a result, the optimal policy shifts from stabilizing the output gap when the shock is transitory to stabilizing price inflation more when the shock is persistent. This rationalizes central banks' supply shock heuristic, but applies even if inflation expectations are rational and cannot de-anchor.

What real wage rigidity changes is that stabilizing the output gap no longer splits a decrease in the real wage between price increases and wage decreases. Instead, when real wages are sufficiently rigid, prices and wages move in the same direction. This creates substantial price and wage inflation. To minimize price and wage inflation costs, monetary policy is willing to create a negative output gap. This motive becomes stronger as the non-markup shock becomes more persistent, since the risk of a sustained price-wage co-movement is then greater.

It is important to emphasize what the paper's results do *not* say. First, they do not say that expectations de-anchoring never justifies departing from output gap stabilization. The paper's first result does imply that de-anchoring risks per se do not create a rationale for engineering a negative output gap to ward off a persistent inflationary shock. Yet this result considers the situation when monetary policy is optimal at all times and has always been in the past. Central banks can make mistakes though. Given that they take decisions in real-time in the face of considerable uncertainty, they are even bound to make decisions that will appear sub-optimal in hindsight. Following such mistakes, whether expectations can de-anchor does make an important difference to optimal policy. Assume, for instance, that monetary policy has been too loose, for instance because the central bank underestimated the output gap in real time (Orphanides 2001). As a result, the output gap has been positive and inflation has run higher than it should have under optimal (full-information) policy. In this case, when expectations are rational, optimal policy simply recommends going back to stabilizing the output gap. But if expectations are backward-looking, optimal policy recommends running a negative output gap to bring inflation down to target faster. Yet, even in this case, the recommendation to run a negative output gap does not follow from the fact that long-run inflation expectations are running above target. Long-term inflation expectations move above target under the fully optimal policy as well. What calls for a negative output gap is if long-term inflation expectations have been running more above target than under the optimal policy. This occurs if the output gap has been running positive.

Second, the paper's results do not say that, absent real wage rigidity, the central bank should not react to persistent productivity and labor supply shocks. Optimal policy is dovish in the absence of sufficient real wage rigidity, but it is dovish in the usual sense of stabilizing the output gap at the expense of stabilizing price inflation. Stabilizing the output gap typically requires increasing interest rates. A recommendation that monetary policy should not react to shocks at all is difficult to obtain in monetary models, and the (intentionally standard) framework of this paper is no exception.[4] There is a common argument for not reacting at all however: the notion that monetary policy works with "long and variable lags" (Friedman 1961). If a shock is short-lived, any benefit of a rate hike may then come too late.[5] The paper's results do not rely on the "long and variable lags" argument.[6] The paper assumes that monetary policy can control aggregate demand without delays and asks whether it should use this ability to stabilize the output gap or to stabilize price inflation.

The paper lies at the crossing of two literatures. The first considers optimal monetary policy in economies with nominal rigidities in several markets, either both price and wage rigidities (Erceg, Henderson, and Levin 2000, Bodenstein, Erceg, and Guerrieri 2008), or price rigidities in several sectors (Benigno 2004, Eusepi, Hobijn, and Tambalotti 2011, La'O and Tahbaz-Salehi 2022, Rubbo 2023, Afrouzi, Bhattarai, and Wu 2024). The second is the adaptive learning literature that reconsiders optimal policy recommendations under backward-looking expectations. (Gaspar, Smets, and Vestin 2010, Molnár and Santoro 2014, Eusepi and Preston 2018, e.g.). Relative to the first literature, I depart from rational expectations and introduce real wage rigidity. Relative to the second, I shift attention away from markup shocks and consider an economy with multiple nominal rigidities.

[4] What is more, a policy of keeping interest rates fixed can be a source of radical instability: self-fulfilling inflation under rational expectations, and inflation spirals under backward-looking expectations and other weaker departures from rational expectations (see, e.g. Dupraz and Marx 2023).

[5] For a recent empirical investigation of the argument, see Buda et al. (2023), who actually find that the impact of monetary policy shocks on output can be seen as early as a few days after the shock.

[6] For this reason, the paper abstains from referring to central banks' supply shock heuristic as the "looking through" heuristic: *"Look through temporary shocks but not persistent ones"*. The term "looking through" is often used to mean what is meant in this paper: stabilizing the output gap instead of inflation. For instance Carney (2017), *"Monetary policy makers may be more inclined to "look through" the direct, temporary effects of commodity price shocks on inflation, which means they do not intend to engineer output gaps to offset the inflationary effects in response."* But it is also used to mean not reacting in the sense of keeping interest rates unchanged. To avoid any ambiguity, the paper mostly avoids the term. On the history of the concept of "looking through", see Nelson (2025).

Blanchard and Galí (2007) and Blanchard and Galí (2010) study the implications of real wage rigidity in New-Keynesian models, highlighting how it breaks the divine coincidence and creates a trade-off between stabilizing inflation and stabilizing the output gap.[7] I show how it rationalizes the notion that the trade-off should be resolved differently depending on whether supply shocks are transitory or persistent. Rudd (2022) expresses skepticism about the importance of inflation expectations for inflation dynamics. I similarly argue that expectations de-anchoring is less central than commonly assumed, but through a very different argument. I maintain the assumption that inflation expectations matter for price and wage setting and therefore for inflation dynamics, but I show that, despite this, de-anchoring risks do not change optimal monetary policy much.

The paper finally connects to the literature on wage-price spirals, as revived by Blanchard (1986) and more recently Lorenzoni and Werning (2023b).[8] It emphasizes the different normative implications of expectations de-anchoring and sticky aspirations (in the form of real wage rigidity), two elements that are typically considered central to a wage-price spiral. While Lorenzoni and Werning (2023b) build their analysis on the case of rational expectations and flexible aspirations, the paper's final section considers a model with both adaptive expectations and real rigidities. In contrast to them, I consider optimal policy under these two assumptions, and highlight the difference between the normative implications of adaptive expectations and real wage rigidity.

More broadly, the paper connects to studies that seek to account for the 2021-2023 inflation surge and its monetary policy response, such as Erceg, Lindé, and Trabandt (2024). They consider the effect of markup supply shocks, while I contrast the different implications of markup and other supply shocks. Bocola et al. (2025) consider a model where expectations can de-anchor because households and firms are imperfectly informed about the central bank's objectives, here as well restricting to markup shocks. Beaudry, Carter, and Lahiri (2023) consider a model in which a discontinuous pivot to a more hawkish policy becomes optimal when inflationary pressures cross a threshold if expectations are formed under level-

[7] On real wage rigidity in mid-scale New-Keynesian models, see e.g. Christiano, Eichenbaum, and Trabandt (2016), who model real wage rigidity through Hall and Milgrom (2008)'s alternating offer bargaining within a search and matching framework.

[8] See also Lorenzoni and Werning (2023a). Bandera et al. (2023) also discuss the role of inflation expectations and second-round effects for the response of monetary policy to supply shocks.

k-thinking, but not if expectations are either rational or adaptive. I rationalize instead a gradual shift to a more hawkish policy when shocks become more persistent through real wage rigidity, which applies when expectations are rational or adaptive.

The paper is organized as follows. Section 1 lays out the backbone of the models used throughout the paper. Section 2 recalls optimal policy results in the standard model under rational expectations. Section 3 considers the model under adaptive expectations and de-anchoring risks. Section 4 considers the model under real wage rigidity.

# 1 Price and Wage Setting

This section presents the backbone of the models used throughout the paper, without making any assumptions on expectations formation for the moment. The model combines price and nominal wage rigidities à la Calvo. Under rational expectations, it is essentially the model of Erceg, Henderson, and Levin (2000), except that it includes five distinct types of supply shocks: price markup shocks, wage markup shocks, productivity shocks, labor-supply shocks, and energy price shocks. To capture energy price shocks, the model allows for an energy input in production.

## 1.1 Production

Firm $i$ produces a good $Z_t^i$ from labor and energy through a CES production function with elasticity of substitution $\epsilon_F$,

$$Z_t^i = A_t Z \left( \frac{\alpha_N}{\alpha_N + \alpha_E} \left( \frac{N_t^{Z,i}}{N^Z} \right)^{1-\frac{1}{\epsilon_F}} + \frac{\alpha_E}{\alpha_N + \alpha_E} \left( \frac{E_t^{Z,i}}{E^Z} \right)^{1-\frac{1}{\epsilon_F}} \right)^{\frac{\epsilon_F}{\epsilon_F - 1}(\alpha_N + \alpha_E)}, \tag{1}$$

where $A_t$ is aggregate productivity, and $Z$, $N^Z$, $E^Z$ are the steady-state values of production, labor and energy. The parameters $\alpha_N$ and $\alpha_E$ correspond to the steady-state labor share and energy share in income, and their sum $\alpha = \alpha_N + \alpha_E$ parameterizes returns to scale. Firm $i$ buys labor at nominal wage $W_t$ and energy at price $P_t^E$. It sells its good $Z_t^i$ to a competitive aggregator, which transforms the differentiated varieties into the final non-energy good $Z_t$

using a standard CES technology with time-varying elasticity of substitution $\theta_t^p$:

$$Z_t = \left( \int_i (Z_t^i)^{\frac{\theta_t^p - 1}{\theta_t^p}} di \right)^{\frac{\theta_t^p}{\theta_t^p - 1}}. \tag{2}$$

The associated price of the consumption good is

$$P_t = \left( \int_i \left( P_t^i \right)^{1-\theta_t^p} di \right)^{\frac{1}{1-\theta_t^p}}. \tag{3}$$

The energy good is produced from labor through the linear production function

$$E_t = \Upsilon_t N_t^E, \tag{4}$$

where $\Upsilon_t$ is an exogenous shock to the energy sector. Energy prices are flexible and the energy sector is competitive, so that

$$P_t^E = W_t / \Upsilon_t. \tag{5}$$

This implies that the relative price between energy and labor is exogenous, driven by exogenous fluctuations in $\Upsilon_t$. Being able to produce more energy from labor lowers the relative energy price.

The energy, labor, and goods markets clear

$$\int_i E_t^{Z,i} di = E_t, \tag{6}$$

$$\int_i N_t^{Z,i} di + N_t^E = N_t, \tag{7}$$

$$C_t = Z_t, \tag{8}$$

where $N_t$ is households' supply of labor and $C_t$ is households' consumption.

## 1.2 Firms' Price-Setting

Prices of $Z$ goods are sticky à la Calvo. Firm $i$ faces a probability $\mu^p$ of not being able to reset its price in any given period. Appendix A shows that when firm $i$ does reset its price, its optimal resetting price is, in log-linear terms

$$p_t^* = (1-\beta\mu^p)\sum_{k=0}^{\infty}(\beta\mu^p)^k\tilde{\mathbb{E}}_t\left[\zeta^p\Big(w_{t+k} - mpl_{t+k} + m_{t+k}^p\Big) + (1-\zeta^p)p_{t+k}\right], \tag{9}$$

where

$$mpl_t = \frac{1}{\alpha}a_t - \frac{1-\alpha}{\alpha}z_t + \frac{\alpha_E}{\alpha}\upsilon_t \tag{10}$$

is the economy-wide marginal product of labor, and $m_t^p$ is an exogenous price markup shock that is a direct function of $\theta_t^p$ and

$$\zeta^p = \frac{1}{1+\frac{(1-\alpha)\theta^p}{\alpha}}, \tag{11}$$

where $\theta^p$ is the steady-state value of $\theta_t^p$. The operator $\tilde{\mathbb{E}}$ denotes firm $i$'s subjective expectations, on which no further assumption is made for the moment. They may or may not be rational.

## 1.3 Unions' Wage-Setting

The composite labor input $N_t$ is a CES aggregator of a continuum of labor types $N_t^j$ with elasticity of substitution $\theta_t^w$. The nominal wage $W_t^j$ of labor type $N_t^j$ is set by labor union $j$, which faces the labor demand

$$N_t^j = \left(\frac{W_t^j}{W_t}\right)^{-\theta_t^w} N_t. \tag{12}$$

Union $j$ represents the interests of workers who value consumption and dislike labor through the preferences

$$\tilde{\mathbb{E}}_0\sum_{t=0}^{\infty}(1-\beta)\beta^t\left(\frac{C_t^{1-\sigma}}{1-\sigma} - \mathcal{F}_t\int_j \frac{(N_t^j)^{1+\psi}}{1+\psi}dj\right), \tag{13}$$

where $C_t$ is aggregate consumption and $\mathcal{F}_t$ is a labor-supply shock.

Nominal wages are sticky à la Calvo. Union $j$ faces a probability $\mu^w$ of not being able to reset its wage every period. Appendix A shows that when it does reset its wage it resets it to

$$w_t^* = (1-\beta\mu^w)\sum_{k=0}^{\infty}(\beta\mu^w)^k\tilde{\mathbb{E}}_t\bigg(\zeta^w\Big(p_{t+k}+mrs_{t+k}+m_{t+k}^w\Big)+(1-\zeta^w)w_{t+k}\bigg), \tag{14}$$

where

$$mrs_t = \psi n_t + \sigma c_t + f_t, \tag{15}$$

is the economy-wide marginal rate of substitution, $m_t^w$ is an exogenous wage markup shock which is a direct function of fluctuations in the elasticity of labor demand $\theta_t^w$, $\theta^w$ is the steady-state value of $\theta_t^w$, and

$$\zeta^w = \frac{1}{1+\psi\theta^w}. \tag{16}$$

### 1.4 Dynamics of inflation and the real wage

From the Calvo staggered pricing assumptions, core price inflation and wage inflation relate to the resetting price (9) and resetting wage (14) through

$$\pi_t^p = \frac{1-\mu^p}{\mu^p}(p_t^*-p_t), \tag{17}$$

$$\pi_t^w = \frac{1-\mu^w}{\mu^w}(w_t^*-w_t). \tag{18}$$

The real wage $\omega_t$ follows the dynamics

$$\omega_t = \omega_{t-1}+\pi_t^w-\pi_t^p. \tag{19}$$

## 1.5 Types of Supply Shocks

The model captures five types of supply shocks: productivity shocks $a_t$, labor supply shocks $f_t$, energy price shocks $\upsilon_t$, price markup shocks $m_t^p$ and wage markup shocks $m_t^w$—also commonly referred to as "price cost-push shocks" and "wage cost-push shocks". Productivity, labor supply, and energy price shocks move the efficient level of output, while markup shocks do not. All shocks are assumed to follow AR(1) processes in log, with autoregressive coefficients $\rho^a$, $\rho^f$, $\rho^\upsilon$, $\rho^{mp}$, $\rho^{mw}$, and standard deviations of the innovations $\sigma_\varepsilon^a$, $\sigma_\varepsilon^f$, $\sigma_\varepsilon^\upsilon$, $\sigma_\varepsilon^{mp}$, $\sigma_\varepsilon^{mw}$.

## 1.6 Welfare

To evaluate different monetary policies, I use the model's microfounded loss function, corresponding to a second-order approximation of the representative household's utility function (13) (Rotemberg and Woodford 1999, Woodford 2003). Regardless of the assumptions made on the private sector's expectations, I always assume that the central bank has rational expectations. Appendix B shows that, assuming the steady-state is efficient (through a constant labor subsidy that undoes steady-state markups), the loss function of the central bank can be written in permanent-consumption equivalent terms as

$$\mathcal{L} = (1-\beta)\frac{1}{2}\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\lambda_x x_t^2 + \lambda_p (\pi_t^p)^2 + \lambda_w (\pi_t^w)^2\right], \tag{20}$$

where $x_t = z_t - z_t^e$ is the output gap defined in distance to the efficient level of output, and where the weights are given by

$$\lambda_x = \sigma + \frac{\psi + 1 - \alpha}{\alpha}, \tag{21}$$

$$\lambda_p = \frac{\theta^p}{\kappa_c^p}, \tag{22}$$

$$\lambda_w = \frac{\alpha\theta^w}{\kappa_c^w}. \tag{23}$$

where

$$\kappa_c^p = \frac{(1-\beta\mu^p)(1-\mu^p)}{\mu^p}\zeta^p, \tag{24}$$

$$\kappa_c^w = \frac{(1-\beta\mu^w)(1-\mu^w)}{\mu^w}\zeta^w. \tag{25}$$

Under Calvo staggered price and wage-setting, the microfounded weights $\lambda_p$ and $\lambda_w$ on inflation and wage inflation arise from relative price and wage dispersion. Under standard calibrations, $\lambda_p$ and $\lambda_w$ are typically much larger than the weight on the output gap $\lambda_x$: the Calvo model assigns very large costs to inflation. The Calvo costs of inflation may be unrealistically high (Nakamura et al. 2018). Throughout the paper, however, I stick to the microfounded Calvo weights. All results are therefore derived under conservatively hawkish preferences. The paper will show that even with those, it is actually difficult to get the model to depart from the dovish recommendation of stabilizing the output gap.

## 1.7 Monetary Policy

The paper's interest lies in how dovish or hawkish a model's optimal policy recommendations are—distinguishing between different shocks and different degrees of shock persistence. To help capture how hawkish or dovish a model's recommendations are, it is useful to consider a special class of monetary policies, defined through the objective that the central bank pursues (Svensson 2003).[9] They are the rules that stabilize a weighted average of core inflation and the output gap

$$(1-\phi)\pi_t^p + \phi x_t = 0, \tag{26}$$

where $\phi$ is between zero and one. The higher $\phi$, the more dovish the policy. Within this class of policies, the best policy corresponds to the value of $\phi$ that minimizes the central bank's loss (20). Focusing on the policies (26) is helpful for capturing a model's recommendations, but it is not necessary. The paper will also consider fully optimal monetary policy.

[9] Svensson argues that particular objective rules can be good characterizations of optimal monetary policy. Here I consider such rules without restricting them to characterize optimal policy—many will not even be close.

I use the terms hawkish and dovish to describe policies, not preferences. A hawkish policy is one that is close to stabilizing inflation. A dovish policy is one that is close to stabilizing the output gap. I will say a model's recommendation is dovish if its optimal policy recommendation is close to a policy rule (26) with $\phi$ close to one. I do not use hawkish and dovish to describe varying preferences.[10] I will always use the microfounded preferences (20) to evaluate policies.

## 1.8 Calibration

Unless otherwise stated, all figures are plotted for the default calibration in the first column of Table 1. The calibration is intended to be as standard as possible. The discount factor $\beta$ corresponds to 2% per year. The labor share is $\alpha_N = 2/3$. The inverse Frisch elasticity of labor supply is $\psi = 2$. The income effect on labor supply is $\sigma = 1$. The steady-state elasticities of both goods and labor demand are $\theta^p = \theta^w = 7$. Firms change their prices every three quarters ($\mu^p = 0.66$) and unions change their wages every five quarters ($\mu^w = 0.8$). The parameters $\alpha_E$ and $\epsilon_F$ related to the use of energy in production are set as follows. The energy share in production is set to $\alpha_E = 0.035$, which is the energy compensation share in value added in the US, averaged over 2015-2024 (BEA-BLS 2026). The elasticity of substitution between labor and energy in production is set to 0.15, as in Chan, Diz, and Kanngiesser (2024). It is in the central part of the low-substitutability range commonly used in the energy-macro literature: 0.03 in Stevens (2015), 0.09 in Adjemian and Darracq Pariès (2008), Backus and Crucini (2000), 0.20 in Montoro (2012), 0.25 in Plante (2014), 0.30 in Natal (2012), and 0.42 in Bodenstein, Guerrieri, and Kilian (2012). However, because the energy shock is specified as a relative-price shock rather than an endowment shock, the calibration of $\epsilon_F$ matters for firms' input mix but not for aggregate output at first order.

[10] If a model has dovish recommendations, it can be said to be a dovish model. However, a model's policy recommendations do not arise from the model's "preferences" (or loss function) alone—as captured by its microfounded loss. They arise from the combination of its loss function and its perspective on how different policies affect the economy.

Table 1: Default Calibration

| | Default Calibration | Exact-Result Calibration |
|---|---|---|
| $\beta$ | 0.995 | - |
| $\alpha_N$ | 2/3 | - |
| $\alpha_E$ | 0.035 | - |
| $\epsilon_F$ | 0.15 | - |
| $\psi$ | 2 | 0.30 |
| $\sigma$ | 1 | 0 |
| $\theta^p$ | 7 | - |
| $\theta^w$ | 7 | 10.0 |
| $\mu^p$ | 0.66 | 0.8 |
| $\mu^w$ | 0.8 | - |
| $\gamma$ | 0.05 | - |

*Note:* The table gives the default calibration used in the paper, as well as one example of an exact-result calibration satisfying the conditions of Propositions 1 and 2. The calibration is quarterly. The learning gain $\gamma$ is only a parameter under adaptive expectations and is irrelevant under rational expectations.

# 2 Standard Recommendations

This section considers whether the standard model under rational expectations rationalizes central banks' supply shock heuristic. It shows that it does for markup shocks, but not for productivity, labor supply, and energy price shocks.

## 2.1 Phillips Curves

Under rational expectations, the price-setting and wage-setting equations can be rewritten to give the price and wage New-Keynesian Phillips curves

$$\pi_t^p = \kappa_c^p(\omega_t - \omega_t^e) + \kappa_y^p x_t + \beta \mathbb{E}_t \pi_{t+1}^p + \kappa_c^p m_t^p, \tag{27}$$

$$\pi_t^w = -\kappa_c^w(\omega_t - \omega_t^e) + \kappa_y^w x_t + \beta \mathbb{E}_t \pi_{t+1}^w + \kappa_c^w m_t^w, \tag{28}$$

where $\omega_t - \omega_t^e$ is the distance of the real wage to the level of real wages $\omega_t^e$ that would obtain in an economy under perfect competition and absent nominal rigidities, where the slopes of the Phillips curves with respect to the real wage $\kappa_c^p$ and $\kappa_c^w$ are defined in (24)-(25), and where the slopes of the Phillips curves with respect to the output gap are

$$\kappa_y^p = \frac{1-\alpha}{\alpha}\kappa_c^p, \tag{29}$$

$$\kappa_y^w = \left(\frac{\psi}{\alpha} + \sigma\right)\kappa_c^w \tag{30}$$

See Appendix C for a derivation.

## 2.2 Should the Central Bank Be Dovish or Hawkish?

Should the central bank respond to supply shocks in a dovish way, stabilizing the output gap? Or should its response be hawkish, stabilizing price inflation instead? Does it depend on the type of supply shock? Does it depend on the persistence of the shock? The responses of the standard model to these questions are summed up in Figure 1. For each type of supply shock, the figure plots the loss function of the central bank as a function of the weight $\phi$ on the output gap in the objective (26) of the central bank, under the assumption that the economy is hit by only this one type of shock. The figure, therefore, illustrates the central bank's trade-off between stabilizing inflation and stabilizing the output gap conditional on a given type of supply shock. The underlying assumption is that the central bank is able to assess the nature of supply shocks—for instance, it is able to tell when inflationary pressures are driven by an increase in the relative price of energy because of a conflict in the Middle East—and that it can condition its response to the nature of the shock if necessary.

Figure 1 plots the loss function for different levels of persistence of the shock, captured by different values of the autoregressive coefficient of the AR(1) process. For a more concrete interpretation, the value of the autoregressive coefficient is expressed through the corresponding shock half-life.[11] The standard deviations of the different supply shocks are normalized such that a one-standard-deviation large innovation to each shock has an effect on output of 1% (in absolute value) in the flexible-price/flexible-wage economy under rational expectations (see Appendix D for details).

For price markup shocks, the model makes prescriptions that are very much in line with

[11] A half-life of $N$ quarters corresponds to a value of $\rho = (1/2)^{\frac{1}{N}}$.

central banks' supply shock heuristic. When the shock is transitory (low half-life), the central bank minimizes its loss by being dovish, i.e. by putting a high weight on stabilizing the output gap (large $\phi$), at the expense of stabilizing price inflation. But as the shock becomes more persistent, the central bank should become more hawkish, placing increasing weight on stabilizing price inflation at the expense of the output gap.

Yet, the recommendation to adopt a more hawkish stance for more persistent shocks is specific to price markup shocks. For non-markup supply shocks, the model concludes instead that the central bank should stabilize the output gap regardless of how persistent the shock is. This contradicts central banks' supply shock heuristic. For wage markup shocks, the recommendation is yet different: the central bank should always stabilize price inflation at the expense of the output gap, even when the shock is transitory.[12]

## 2.3 Why Stabilizing the Output Gap Works Well

Why is stabilizing the output gap a good policy in response to productivity, labor-supply and energy price shocks? Two observations are key. First, when there is both price and wage rigidity, monetary policy ultimately has little effect on the dynamics of the real wage. To see this, take the difference between the wage (28) and price (27) Phillips curves to get the dynamics of the real wage as

$$\Delta_t = -\left(\kappa_c^w + \kappa_c^p\right)(\omega_t - \omega_t^e) + \left(\kappa_y^w - \kappa_y^p\right)x_t + \beta\mathbb{E}_t\Delta_{t+1} + \kappa_c^w m_t^w - \kappa_c^p m_t^p. \tag{31}$$

where $\Delta_t$ is the growth rate of real wages

$$\Delta_t = \omega_t - \omega_{t-1}. \tag{32}$$

[12]The difference between price and wage markup shocks comes from the fact that the central bank objective (26) features price inflation and not wage inflation. A positive price-markup requires a fall in the real wage, which optimal policy recommends to implement through positive price and wage inflation with price inflation above wage inflation. A positive wage-markup shock requires a rise in the real wage, which optimal policy recommends to implement through positive price and wage inflation with price inflation *below* wage inflation. For wage markup shocks, stabilizing price inflation is therefore not too far from optimal policy. A policy that stabilizes *wage* inflation would not be too far from optimal policy against price markup shocks.

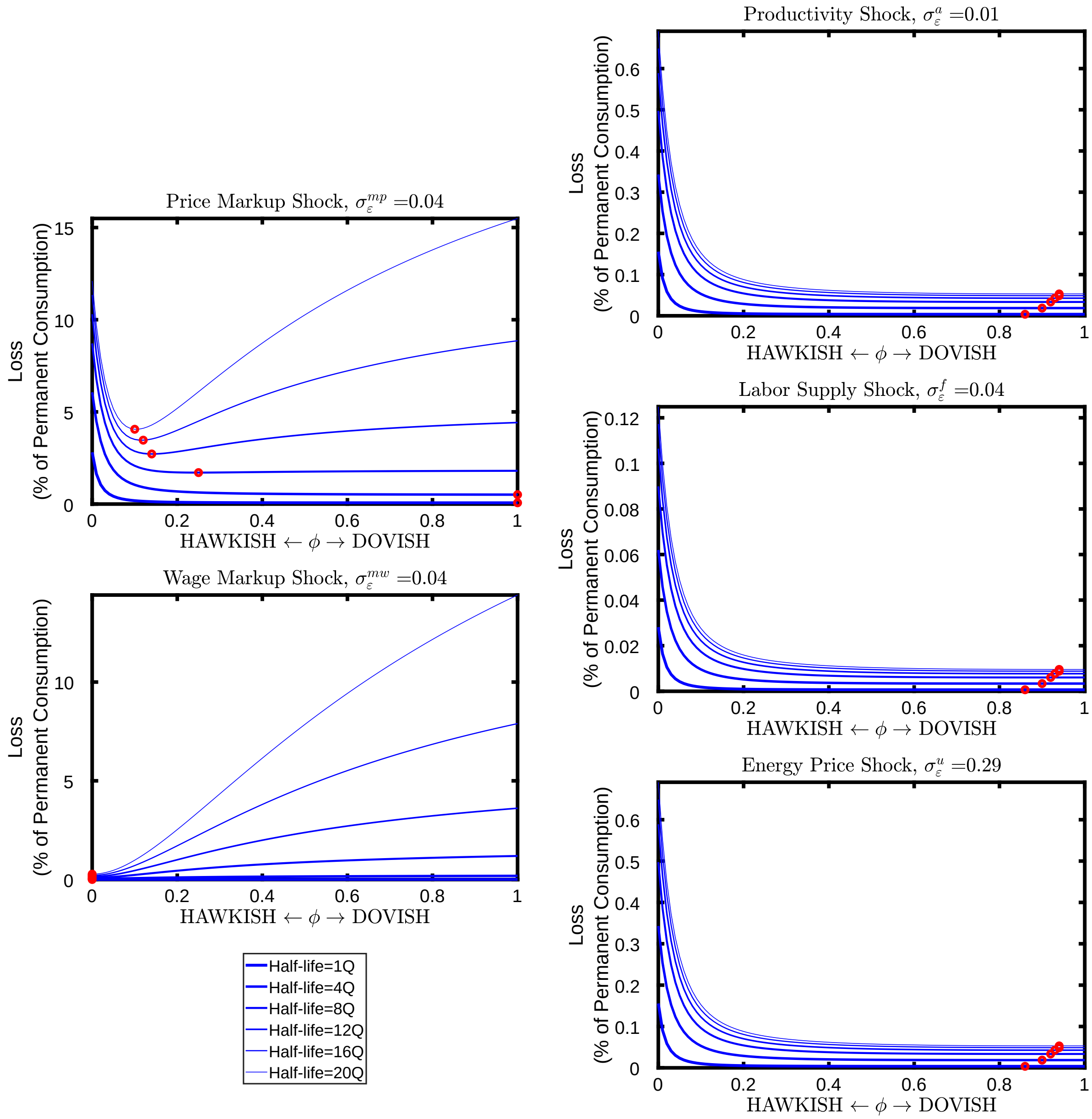



Figure 1: Loss Function under Rational Expectations

*Note: For each type of supply shock, the figure plots the loss function of the central bank (20) as a function of the weight $\phi$ on the output gap in the objective (26) of the central bank, under the assumption that the economy is hit by this one type of shock only. It does so for different levels of persistence of the shock, captured by the half-life of the AR(1) process. On each curve, the red dot corresponds to the minimum of the curve, that is the optimal policy within the class of policies (26). The calibration is given in the "Default Calibration" column of Table 1.*

Monetary policy can affect the path of the real wage by allowing for a larger or smaller output gap $x_t$, but the output gap affects the growth rate of wages through the difference between the two slopes $\kappa_y^w - \kappa_y^p$. If the price and wage Phillips curves have about the same slope, then monetary policy has little effect on the dynamics of the real wage.

Intuitively, higher aggregate demand pushes both firms to increase their prices (because of decreasing returns to scale in production) and unions to increase their wages (because of the decreasing marginal utility of labor and a possible income effect on labor supply). When $\kappa_y^w = \kappa_y^p$, higher aggregate demand pushes prices and wages by the same amount, and the real wage is unaffected. Even beyond this particular case, the effect on the real wage is small—at least unless there is a very strong asymmetry between the degrees of price and wage rigidity. Ultimately, what monetary policy can affect is not so much the real wage but whether the change in the real wage occurs through a fall in nominal wages, an increase in prices, or some combination of the two. The small responsiveness of real wages to monetary policy shocks is emphasized by Christiano, Eichenbaum, and Evans (2005), who argue on this basis for the importance of including both price and wage rigidities in monetary models.

Second, stabilizing the output gap turns out to deliver a very good split of a real wage decrease between price increases and wage decreases. To see this, define the weighted average of price and wage inflation

$$\pi_t^{DC} = \left(\frac{\kappa_c^w}{\kappa_c^p + \kappa_c^w}\right)\pi_t^p + \left(\frac{\kappa_c^p}{\kappa_c^p + \kappa_c^w}\right)\pi_t^w, \tag{33}$$

which satisfies

$$\pi_t^{DC} = \left(\frac{\kappa_c^w \kappa_y^p + \kappa_c^p \kappa_y^w}{\kappa_c^w + \kappa_c^p}\right) x_t + \beta \mathbb{E}_t \pi_{t+1}^{DC} + \left(\frac{\kappa_c^p \kappa_c^w}{\kappa_c^w + \kappa_c^p}\right)(m_t^p + m_t^w). \tag{34}$$

In response to productivity and labor-supply shocks, stabilizing the output gap stabilizes the weighted average $\pi_t^{DC}$. Following Rubbo (2023), I call the index the Divine Coincidence index.[13] In itself, there is nothing particularly divine about the fact that stabilizing the output gap stabilizes a particular weighted average of price and wage inflation. What *is*

[13]Rubbo uses the term to define a weighted average of price inflation rates across sectors in a multisector model with input/output linkages and wage flexibility. The idea is the same however.

divine about $\pi_t^{DC}$ is that stabilizing it turns out to be very close to minimizing the distortions arising from price and wage inflation.[14]

To start with, if $\pi_t^{DC}$ remains constant, it means price inflation and wage inflation have different signs: a decrease in the real wage is split between price increases and wage decreases. This is already a good idea, better than relying only on price increases or on wage decreases alone, since welfare losses are quadratic in price and wage inflation. But better still, the exact weights in $\pi_t^{DC}$ have very good properties. Stabilizing $\pi^{DC}$ is closer to stabilizing price inflation the more rigid prices are relative to wages, making the adjustment occur through nominal wages instead. Since price dispersion is relatively more costly the more rigid prices are, this is good. A particular set of calibrations buttresses this point, as shown in Woodford (2003) and Galí (2008).

**Proposition 1.** *Consider the model under rational expectations. If $\kappa_y^w = \kappa_y^p$ and $\theta^p = \alpha\theta^w$, then the optimal monetary policy in response to productivity, labor supply and energy price shocks is to stabilize the output gap at all times $x_t = 0$, under both commitment and discretion.*

To see why the result holds, make the change of variables from $(\pi_t^p, \pi_t^w)$ to $(\bar{\pi}_t, \Delta_t)$, where $\bar{\pi}_t$ is the following weighted average of price and wage inflation

$$\bar{\pi}_t = \frac{\lambda_p}{\lambda_p + \lambda_w}\pi_t^p + \frac{\lambda_w}{\lambda_p + \lambda_w}\pi_t^w. \tag{35}$$

The central bank's loss can then be rewritten as

$$\mathbb{W} = -\frac{1}{2}(1-\beta)\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\lambda_x (x_t)^2 + (\lambda_p + \lambda_w)\bar{\pi}_t^2 + \frac{1}{\lambda_p^{-1} + \lambda_w^{-1}}\Delta_t^2\right]. \tag{36}$$

As explained before, if $\kappa_y^w = \kappa_y^p$ then the dynamics of the real wage is independent of monetary policy and the central bank trades off stabilizing $\bar{\pi}_t$ and stabilizing $x_t$. Now, if in addition $\lambda_p \kappa_c^p = \lambda_w \kappa_c^w$, which is equivalent to $\theta^p = \alpha\theta^w$, then $\bar{\pi}_t$ corresponds to the Divine Coincidence index $\pi_t^{DC}$, so there is no trade-off between stabilizing $\bar{\pi}_t$ and stabilizing the output gap $x_t$ for any shock that enters the Phillips curves through $\omega_t^e$ only: productivity,

[14] Divine as this is, even in the case of Proposition 1 the optimal policy does not achieve the first best, in contrast to the case of the divine coincidence under price rigidity alone.

labor supply, and energy price shocks. For these shocks, it is possible to set both $\bar{\pi}_t = 0$ and $x_t = 0$ at all times, which minimizes the loss function (36).

While the exact optimality of stabilizing the output gap only obtains in the particular cases of Proposition 1, stabilizing the output gap remains very close to the optimal monetary policy under standard calibrations. Crucially, since none of the reasons why stabilizing the output gap is a good policy hinge on the shock being transitory, it applies similarly to persistent shocks.

The exact optimality of stabilizing the output gap also does not hinge on a flat Phillips curve. Proposition 1 requires the wage and price Phillips curves to have equal slopes, but this common slope can be arbitrarily steep. This highlights that a steep Phillips curve in itself does not necessarily call for a more hawkish monetary policy once there is both price and wage rigidity. By the same logic, the possibility that the Phillips curve is convex and steepens at high levels of inflation does not by itself call for a more hawkish policy if the wage Phillips curve steepens in tandem at high levels of wage inflation.[15]

## 2.4 Other Costs of Price and Wage Inflation?

The exact optimality of stabilizing the output gap in Proposition 1 relies on taking into account the welfare costs of wage inflation. Stabilizing price inflation only shifts the real-wage adjustment to nominal wages, which shifts welfare costs to wage dispersion. These welfare costs are embedded in the micro-founded loss function (20) and are the natural counterpart of the welfare costs of price inflation. However, the fact that inflation costs amount to inefficient dispersion costs reflects the underlying assumption of Calvo price and wage setting. While inefficient dispersion is one of the main costs of inflation identified in the literature, this raises the question of whether alternative rationales for the costs of price and wage inflation would imply the same relative weights.

Evidence from household surveys puts forward other costs of price inflation. Stantcheva (2024), building on Shiller (1997), finds that the main reason households report for disliking

[15]For recent work on the convex price Phillips curve, see e.g. Blanco et al. (2024) and Benigno and Eggertsson (2023). On the implication of a convex Phillips curve for optimal monetary policy, see e.g. Karadi et al. (2024), Harding et al. (2026), Ascari et al. (2026).

inflation is that it erodes their purchasing power, as they often believe that wages rise less than prices. Under this interpretation of the costs of inflation, the assumption in the Calvo loss function (20) that wage inflation is also costly is robust: higher inflation decreases real wages, but lower nominal wages do too.[16]

## 2.5 Abstracting from Wage Inflation Costs

It remains useful to assess how much the good properties of stabilizing the output gap worsen if one abstracts from the costs of wage inflation. Figure 2 shows that stabilizing the output gap remains close to optimal even when abstracting from the costs of wage inflation. The figure replicates Figure 1, but this time decomposing the central bank's loss (20) between its three components: output-gap deviations $L_x = \lambda_x \mathbb{E}_0 x_t^2$, price inflation deviations $L_p = \lambda_p \mathbb{E}_0 (\pi_t^p)^2$, and wage inflation deviations $L_w = \lambda_w \mathbb{E}_0 (\pi_t^w)^2$. It also plots the loss $L_x + L_p$ that combines output-gap and price inflation costs but abstracts from wage inflation costs. To maintain readability, the figure is plotted for shocks with a half-life of 16 quarters only.

Against non-markup shocks, wage inflation costs are the highest for very hawkish policies that focus on price inflation (low $\phi$), so abstracting from these costs reduces the undesirability of such hawkish policies. But hawkish policies are still the costliest ones and more costly than the dovish policies that focus on stabilizing the output gap (high $\phi$). While the exact optimality of stabilizing the output gap no longer holds even under the set of calibrations in Proposition 1, stabilizing the output gap is still close to optimal.

Why is stabilizing the output gap still a good policy? The microfounded Calvo weights are conservatively hawkish, putting a large weight on price inflation and a small weight on the output gap. Yet, stabilizing price inflation requires very large variations in the output gap. As a result, for hawkish policies the loss from output gap variations $\lambda_x x_t^2$ is very large.

[16] Since households often perceive nominal wage gains as earned through their performance on the job, whereas price inflation is seen as beyond their control, one could argue for stabilizing price inflation on the basis that households will be more dissatisfied with a large nominal wage increase that is then taken away by price inflation than with a modest nominal wage increase. This argument, however, becomes weaker when stabilizing price inflation requires outright declines in nominal wages, which are likely to be salient and strongly disliked. Workers' reluctance to nominal wage cuts is an argument for letting real wage cuts occur through price inflation (Tobin 1972).

This can be seen in Figure 3, which plots the response of the economy to a persistent increase in the price of energy under four policies: stabilizing price inflation, stabilizing the output gap, the fully optimal policy, and the optimal policy abstracting from the costs of wage dispersion. The latter two are optimal policies under commitment, characterized in Appendix E. Stabilizing price inflation requires a large drop in the output gap. Under the microfounded loss function, stabilizing price inflation only trades inefficient price dispersion for inefficient wage dispersion. This has little benefit and only brings the large output gap costs. The optimal monetary policy is therefore very close to stabilizing the output gap. Under the loss function that abstracts from the costs of wage dispersion, there is some benefit in replacing inefficient price dispersion with wage dispersion, but this benefit still comes at a large output gap cost. Optimal policy allows for a slightly negative output gap, but it is still much closer to stabilizing the output gap than to stabilizing price inflation.

# 3 Adaptive Expectations and De-anchoring Risks

That the standard model does not capture central banks' supply shock heuristic may not be surprising: because it assumes rational expectations, it does not capture de-anchoring risks. Yet the risk of expectations de-anchoring is the main rationale put forward to justify a shift to a more hawkish policy when shocks are persistent. This section drops the assumption of rational expectations and assumes instead that inflation expectations are adaptive, so that they can de-anchor. It shows that de-anchoring risks do not change the model's dovish recommendations: stabilizing the output gap remains very close to optimal for non-markup supply shocks, however persistent the shock.

## 3.1 Expectation Formation

I assume that firms and unions form expectations according to adaptive expectations. Adaptive expectations are a particular form of adaptive learning when households and firms learn only about the average inflation rate, without learning the relationship between inflation and its potential predictors. I model adaptive expectations following the "long-horizon ap-

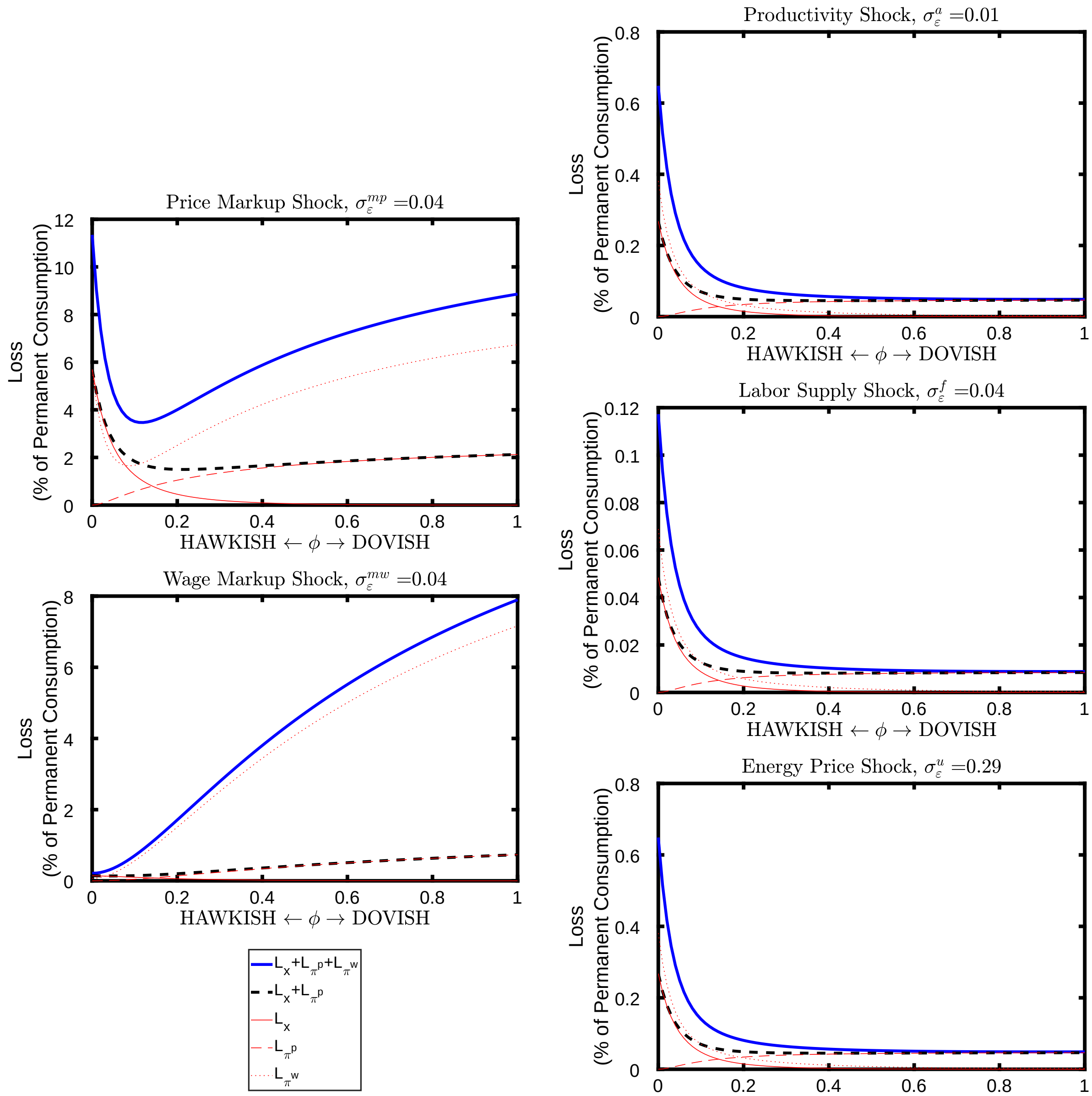



Figure 2: Decomposition of the Loss Function under Rational Expectations

*Note: For each type of supply shock, the thick plain line plots the loss function of the central bank (20) as a function of the weight $\phi$ on the output gap in the objective (26) of the central bank, under the assumption that the economy is hit by this one type of shock only. The thick dashed line plots the loss function abstracting from the costs arising from wage inflation. The thin lines, plain, dashed and dotted, show the losses arising from the output gap, from price inflation, and from wage inflation. The calibration is given in the "Default Calibration" column of Table 1. The persistence of the shock corresponds to a half-life of 16 quarters.*

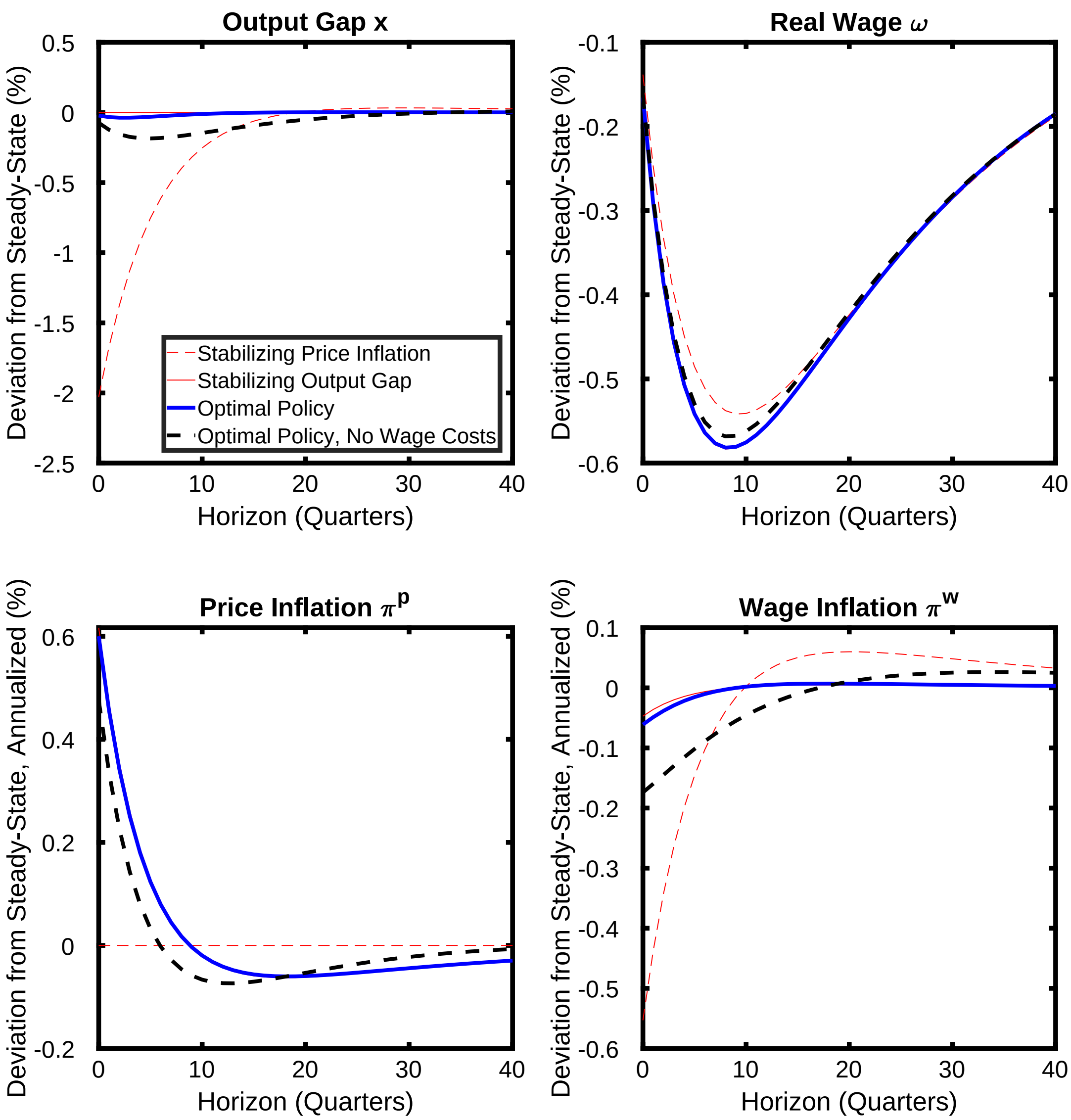



Figure 3: Response to an Increase in Energy Prices under Rational Expectations

*Note: The figure plots the response of the output gap, price inflation, wage inflation and the real wage to a persistent increase in the price of energy with a half-life of 16 quarters. For each variable, the panel plots the response under 4 policies: stabilizing price inflation, stabilizing the output gap, the optimal policy and the optimal policy abstracting from wage dispersion costs. The calibration is given in the "Default Calibration" column of Table 1.*

proach" of Preston (2005) (in a model with price rigidity only).[17] Firms and unions form expectations about all variables that matter to their optimal resetting price and wage in equations (9)-(14). They perfectly observe all time-$t$ variables. They form expectations on future prices and future nominal wages from the current price and current nominal wage, together with their expectations of future price and wage inflation

$$\tilde{\mathbb{E}}_t(p_{t+k}) = p_t + \sum_{i=1}^{k} \tilde{\mathbb{E}}_t(\pi^p_{t+i}), \tag{37}$$

$$\tilde{\mathbb{E}}_t(w_{t+k}) = w_t + \sum_{i=1}^{k} \tilde{\mathbb{E}}_t(\pi^w_{t+i}). \tag{38}$$

Firms and unions need to form expectations on all exogenous variables that enter their program: price inflation $\pi^p$, wage inflation $\pi^w$, aggregate demand $z$ for firms and aggregate employment $n$ for unions, the shocks $a, \upsilon, m^p$ for firms and the shocks $f$ and $m^w$ for unions. To focus on the de-anchoring of inflation expectations, I assume that they expect output, employment and the shocks to remain constant at their steady-state values. I assume that their expectations of price and wage inflation are the same at all future horizons. They are formed under constant-gain learning

$$\pi^{p*}_t = \gamma \pi^p_t + (1-\gamma)\pi^{p*}_{t-1}, \tag{39}$$

$$\pi^{w*}_t = \gamma \pi^w_t + (1-\gamma)\pi^{w*}_{t-1}, \tag{40}$$

where $\gamma$ is the constant learning gain that I assume is the same for both price and wage inflation.

[17] The alternative is to follow the "Euler equation approach" that replaces the forward-looking expectations in the Phillips curves (27) and (28) by adaptive versions. Since the derivation of the Phillips curves (27) and (28) makes use of the assumption of rational expectations however, this can be internally inconsistent.

## 3.2 Phillips Curves

Appendix F derives the price and wage Phillips curves under adaptive expectations,

$$\pi_t^p = \kappa_c^p\left(\omega_t - \omega_t^e\right) + \kappa_y^p x_t + \zeta^p \beta(1-\mu^p)\omega_t + \frac{\beta(1-\mu^p)}{1-\beta\mu^p}\left(\pi_{t-1}^{p*} + \zeta^p \Delta_{t-1}^*\right) + \kappa_c^p m_t^p, \tag{41}$$

$$\pi_t^w = -\kappa_c^w\left(\omega_t - \omega_t^e\right) + \kappa_y^w x_t - \zeta^w \beta(1-\mu^w)\omega_t + \frac{\beta(1-\mu^w)}{1-\beta\mu^w}\left(\pi_{t-1}^{w*} - \zeta^w \Delta_{t-1}^*\right) + \kappa_c^w m_t^w, \tag{42}$$

where $\Delta_t^* = \pi_t^{w*} - \pi_t^{p*} = \gamma\Delta_t + (1-\gamma)\Delta_{t-1}^*$.

Expectations of both price and wage inflation enter both Phillips curves. Firms need to form expectations on price inflation to assess what the price of their competitors will be, and they need to form expectations on wage inflation to assess what their nominal marginal cost will be. Under rational expectations, expectations of wage inflation can be derived from expectations of price inflation and expectations of future real wages, which themselves depend on expectations of future output and shocks. But doing so requires knowledge of general equilibrium relationships that firms are here assumed not to have. Some variants of adaptive learning can seemingly bypass the need for firms to form expectations on wage inflation. I consider such an alternative later on.

## 3.3 Should the Central Bank Be Dovish or Hawkish?

Does the possibility for expectations to de-anchor recover central banks' supply shock heuristic? Figure 4 represents the ranking of the different policies (26) in the same way as in Figure 1, but this time under adaptive expectations. The calibration is the same, given in the first column of Table 1. The new parameter, the learning gain $\gamma$, is set to 0.05 quarterly. It is higher than most values found in papers that estimate a similar constant learning gain. Milani (2007) and Orphanides and Williams (2005) find gains of 0.02, and Nagel (2024) of 0.016. Dupraz and Marx (2023) find it to be 0.042 using households' five-year-ahead inflation expectations in the Michigan survey over 1984-2007.

The results are broadly unchanged. Against persistent markup shocks, dovish policies become very costly. But against non-markup supply shocks, even very dovish policies continue to have a small cost, and are considerably less costly than very hawkish policies. The loss function is now slightly increasing with $\phi$ for values of $\phi$ getting closer to 1. But the increase is small and the loss function is essentially flat at high values of $\phi$. In practical terms the optimal policy is still very close to stabilizing the output gap, as can be seen in Figure 5, which plots the response of the economy to a persistent increase in energy prices under the same four policies as in Figure 3 for rational expectations: stabilizing the output gap, stabilizing price inflation, the fully optimal policy and the optimal policy abstracting from the welfare costs of wage dispersion. (The latter two are characterized in Appendix G.) In the first 40 quarters plotted on the figure, the optimal policy is if anything even closer to stabilizing the output gap than under rational expectations. The slightly increasing loss for high $\phi$ in Figure 4 comes from the cumulative deviations up to very high horizons of the impulse response function.

In addition, the fact that the loss function is not minimized for $\phi = 1$ is actually calibration-specific. Stabilizing the output gap is still exactly optimal in a particular set of non-extreme calibrations, as the next section shows.

## 3.4 Why Stabilizing the Output Gap Still Works Well

The reasons why stabilizing the output gap still works well are essentially the same as under rational expectations. First, it is still the case that monetary policy has ultimately little effect on the real wage. To see this, consider the case where the frequency of price and wage changes is the same, $\mu^w = \mu^p$—denote it $\mu$. Taking the difference between the wage Phillips curve (42) and price Phillips curve (41) gives the dynamics of the real wage as

$$\Delta_t = -\left(\kappa_c^w + \kappa_c^p\right)(\omega_t - \omega_t^e) + \left(\kappa_y^w - \kappa_y^p\right)x_t - \beta(1-\mu)(\zeta^w + \zeta^p)\omega_t + \frac{\beta(1-\mu)}{1-\beta\mu}(1 - \zeta^w - \zeta^p)\Delta_{t-1}^* + \kappa_c^w m_t^w - \kappa_c^p m_t^p, \tag{43}$$

If $\kappa_y^w = \kappa_y^p$, then the real wage is independent of monetary policy. Once again, what monetary policy can affect is not the real wage, but whether real wage decreases occur through decreases in nominal wages or increases in prices.

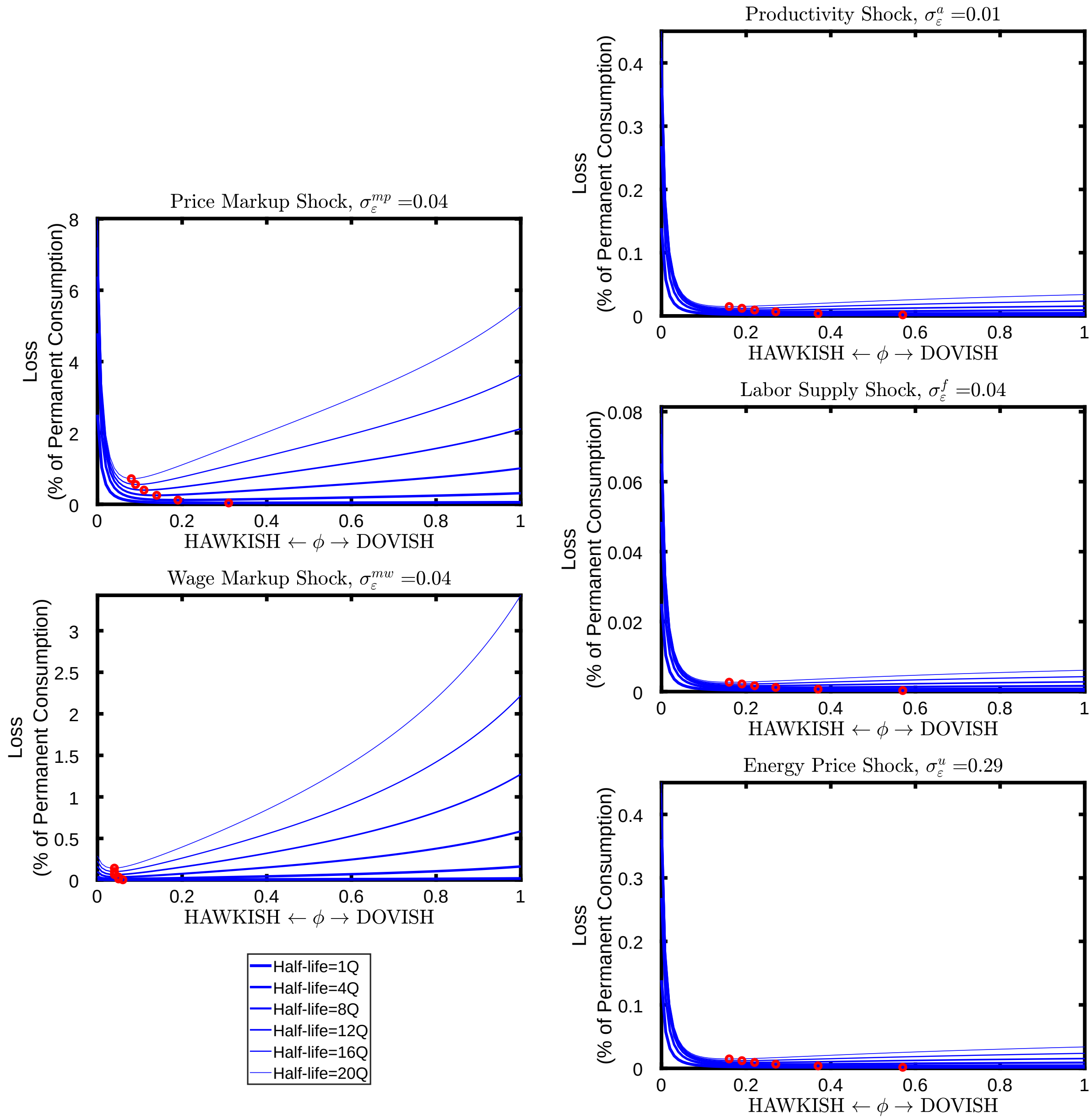



Figure 4: Loss Function under Adaptive Expectations

*Note: For each type of supply shock, the figure plots the loss function of the central bank* (20) *as a function of the weight $\phi$ on the output gap in the objective* (26) *of the central bank, under the assumption that the economy is hit by this one type of shock only. It does so for different levels of persistence of the shock, captured by the half-life of the AR(1) process. On each curve, the red dot corresponds to the minimum of the curve, that is the optimal policy within the class of policies* (26)*. The calibration is given in the "Default Calibration" column of Table 1.*

Second, it is still the case that stabilizing the output gap delivers a good split of the real wage between price increases and wage decreases. Still restricting to the case $\mu^w = \mu^p = \mu$, and noticing that $\kappa_c^w \zeta^p = \kappa_c^p \zeta^w$ in this case, the divine coincidence index (33) satisfies

$$\pi_t^{DC} = \left( \frac{\kappa_c^w \kappa_y^p + \kappa_c^p \kappa_y^w}{\kappa_c^w + \kappa_c^p} \right) x_t + \frac{\beta(1-\mu)}{1-\beta\mu} \pi_{t-1}^{DC*} + \left( \frac{\kappa_c^p \kappa_c^w}{\kappa_c^w + \kappa_c^p} \right) (m_t^p + m_t^w), \tag{44}$$

where $\pi_t^{DC*} = \left( \frac{\kappa_c^w}{\kappa_c^w + \kappa_c^p} \right) \pi_t^{p*} + \left( \frac{\kappa_c^p}{\kappa_c^w + \kappa_c^p} \right) \pi_t^{w*}$ is the long-term expected Divine Coincidence index, which satisfies $\pi_t^{DC*} = \gamma \pi_t^{DC} + (1-\gamma) \pi_{t-1}^{DC*}$. Stabilizing the output gap in response to non-markup supply shocks still stabilizes the Divine Coincidence index, although this now holds exactly only when restricting to the case $\mu^w = \mu^p$.

In turn, and just like under rational expectations, if in addition $\theta^p = \alpha \theta^w$, then the Divine Coincidence index corresponds to the weighted average (35) of price and wage inflation, and stabilizing it is the fully optimal policy that minimizes the loss function (36).[18] The three conditions $\mu^w = \mu^p$, $\theta^p = \alpha \theta^w$, and $\kappa_y^w = \kappa_y^p$ are equivalent to the conditions stated in the proposition below.

**Proposition 2.** *Consider the model under adaptive expectations. If $\mu^w = \mu^p$, $\theta^p = \alpha \theta^w$, $\psi = 1 - \alpha$ and there is no income effect on labor supply $\sigma = 0$, then the optimal monetary policy in response to productivity, labor supply and energy price shocks is to stabilize the output gap at all times $x_t = 0$.*

The conditions of Proposition 2 are the same as the conditions of Proposition 1, plus the extra condition that the frequencies of price and wage changes are the same, $\mu^w = \mu^p$. They are therefore more restrictive, imposing further symmetry between price and wage rigidity for the exact optimality of stabilizing the output gap to hold.[19]

But the underlying intuition is the same as in the case of rational expectations. Under adaptive expectations, letting price inflation overshoot its target increases long-term inflation expectations, which creates persistently high inflation. Yet, it does not follow that a hawkish policy of stabilizing price inflation is preferable. Stabilizing price inflation still only replaces

[18]Stabilizing the output gap is once again the optimal policy under both discretion and commitment, but under adaptive expectations there is never any difference between discretion and commitment anyway.

[19]No income effect on labor supply $\sigma$ does not need to be interpreted as an infinite intertemporal elasticity of substitution. See e.g. Gali (2011) for an approach to calibrating the two independently of each other.

inefficient price dispersion by inefficient wage dispersion, and still comes at a large cost to the output gap.

Proposition 2 puts no restriction on the value of the learning gain $\gamma$. It holds regardless of how strongly expectations move with current inflation, i.e. of how de-anchored expectations are.

### 3.5 Past Mistakes and Course Correction

The previous result shows that stabilizing the output gap remains optimal when expectations are backward-looking and can de-anchor, but it is important to highlight what the result does *not* say. The result concerns the case when monetary policy is optimal at all times and has always been optimal in the past. Then, de-anchoring risks make little change to optimal policy, which should seek to stabilize the output gap at all times. Yet backward-looking expectations do matter for how the central bank should react if it realizes that it has made mistakes in the past, departing from stabilizing the output gap. Such mistakes—or at least what appears to be mistakes in hindsight—are bound to happen given that central banks make decisions in real time in the face of considerable uncertainty.

Figure 6 plots the response of the economy to the same persistent increase in the price of energy as in Figure 5, but assumes that in the first ten quarters following the shock, monetary policy stabilizes *output* instead of the output gap, creating a positive output gap. Monetary policy departs from optimal policy, but it does not need to be because it actively wants to overheat the economy. It may be because the central bank wanted to close the output gap but underestimated the drop in natural output caused by the shock. (Orphanides 2001) argues this is what happened in the US in the 1970s.

When the central bank realizes it has run too accommodative a policy and shifts to optimal policy, creating a negative output gap is then justified. The cost of a negative output gap is outweighed by the benefit of speeding up the return of inflation to the target. Optimal policy does not attempt to bring price inflation all the way to what it would have been if the policy had been optimal from the beginning however. In particular, wage inflation remains positive. But the policy shift is sharp, allowing the dynamics of inflation expectations to reverse.

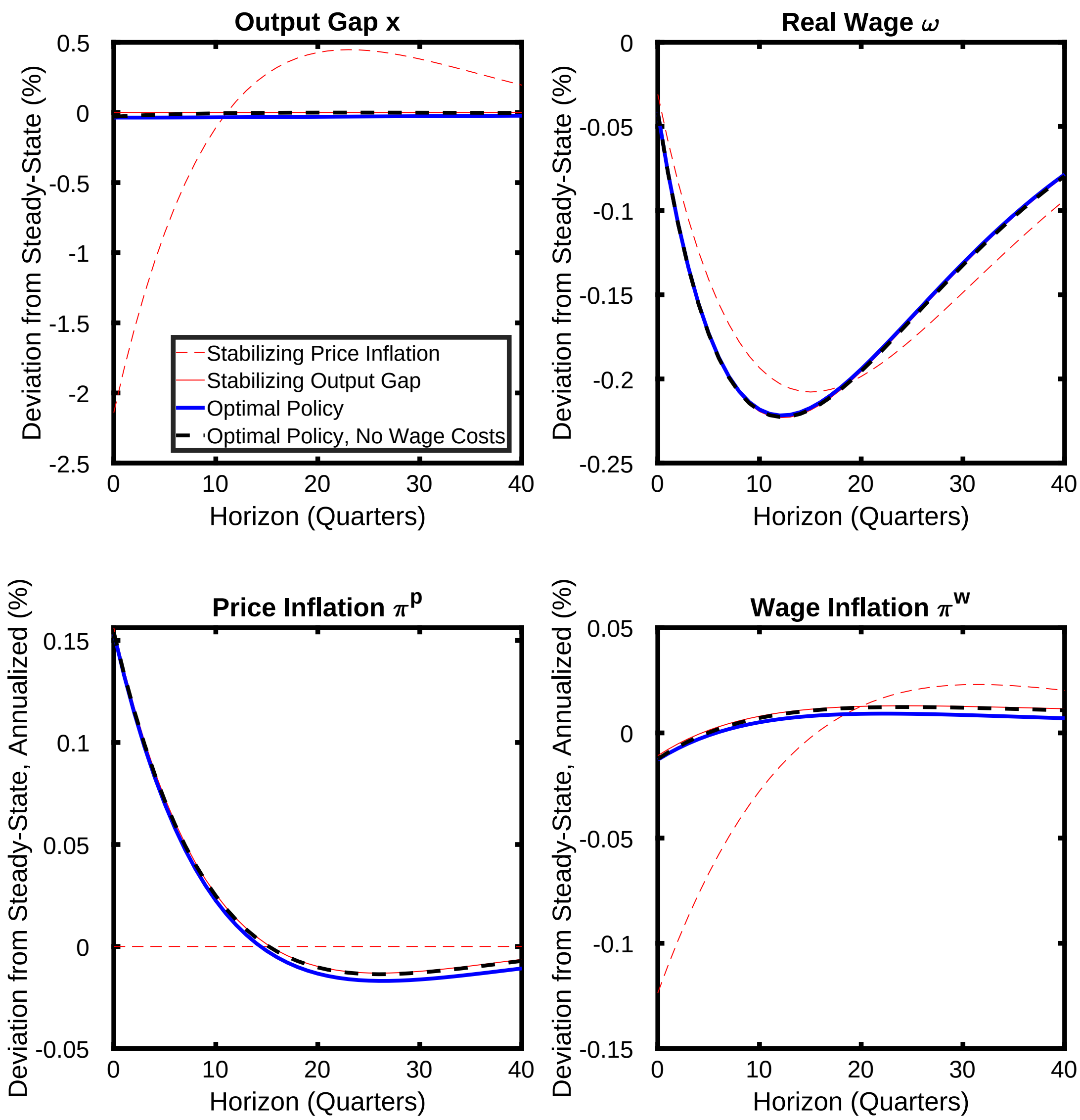



Figure 5: Response to an Increase in Energy Prices under Adaptive Expectations

*Note: The figure plots the response of the output gap, price inflation, wage inflation and the real wage to a persistent increase in the price of energy with a half-life of 16 quarters. For each variable, the panel plots the response under 4 policies: stabilizing price inflation, stabilizing the output gap, the optimal policy and the optimal policy abstracting from wage dispersion costs. The calibration is given in the "Default Calibration" column of Table 1.*

The recommendation to tolerate a negative output gap is driven by backward-looking expectations and does not arise under rational expectations. There, optimal monetary policy from quarter 10 onward is very little affected by past mistakes. When switching to optimal policy, the central bank should cut the output gap to zero, but not create a negative output gap, as shown in Appendix H. This is because rational expectations make the dynamics very forward-looking and little dependent on past state variables.[20] Under adaptive expectations in contrast, backward-looking inflation expectations make the past matter.

The reversal of inflation expectations—which include long-term expectations here since expectations are the same at all horizons—fits the narrative that a negative output gap is needed to re-anchor expectations. Yet the fact that long-term inflation expectations increase above target is no sign that policy has been non-optimal: they increase above target under optimal policy as well, just less so. The need for a negative output gap does not follow from long-term inflation expectations increasing above target. It arises if long-term inflation expectations have been increasing more than they should have under optimal policy, which happens if the output gap has run positive.

## 3.6 Robustness to an Alternative Assumption on Learning

Equation (38) assumes that firms and unions expect that future nominal wages will be current nominal wages plus their expectations of future wage inflation. Alternatively, one can assume they form their expectations of future nominal wages by thinking first in terms of future *real* wages. They learn the level of future real wages through

$$\omega_t^* = \gamma\omega_t + (1-\gamma)\omega_{t-1}^*. \tag{45}$$

Firms then still need to form expectations on future price inflation in order to expect their competitors' future prices. But their expectations of future nominal wages are their expectations of future real wages plus their expectations of the future price level that they derive

[20]The economy under rational expectations is not entirely forward-looking though. The real wage is a state variable and since optimal policy is taken under commitment, bygones are not treated as bygones. But the backward-looking component of the system does not make past mistakes have much influence on future policy.

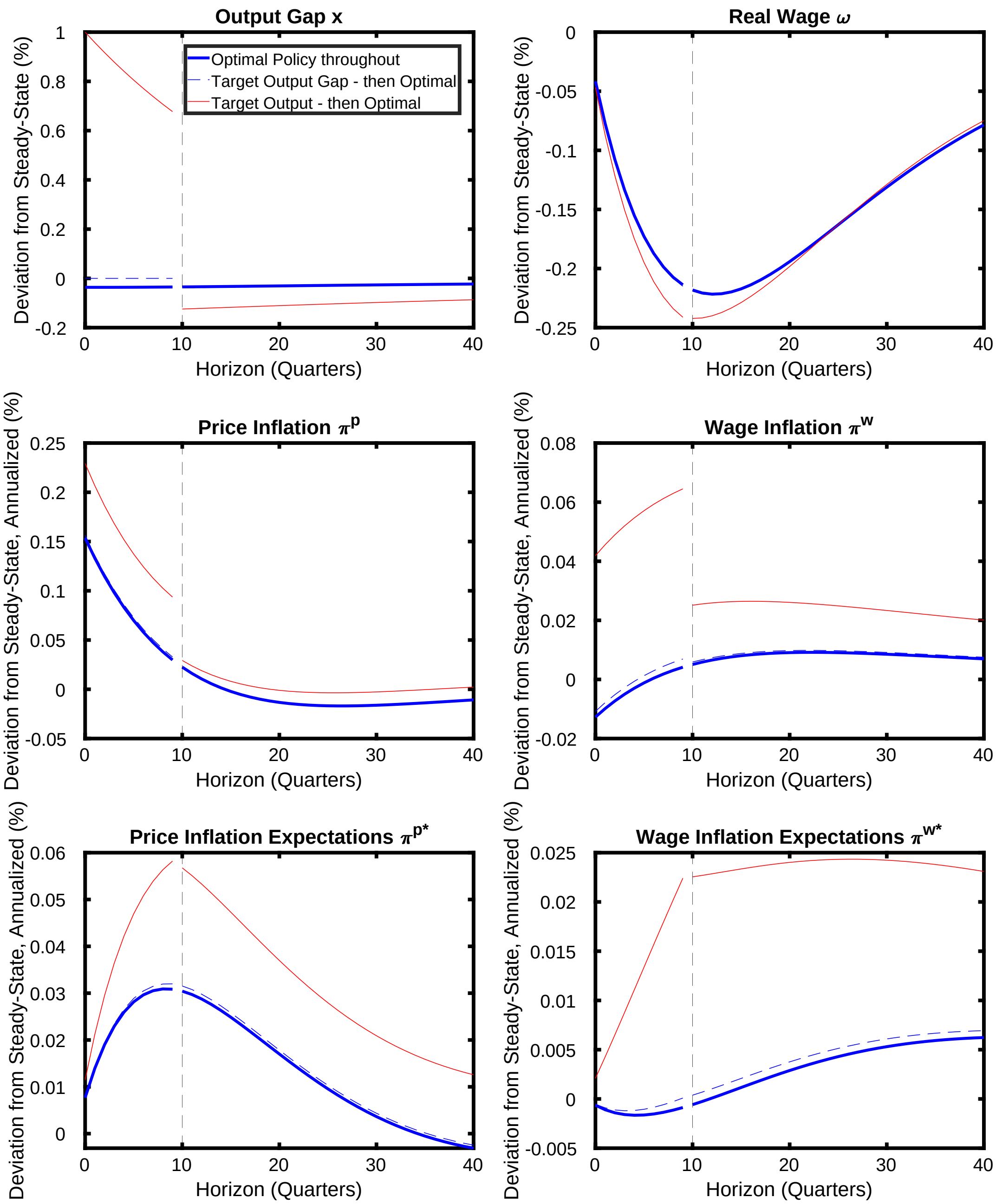



Figure 6: Optimal Policy After Overly Accommodative Policy, Adaptive Expectations

*Note: The figure plots the response of the output gap, the real wage, price inflation, wage inflation, price inflation expectations and wage inflation expectations to a persistent increase in the price of energy with a half-life of 16 quarters, under three scenarios. First, monetary policy keeps the output gap constant at zero from quarters 0 to 10, then switches to fully optimal policy. Second, monetary policy keeps output constant at its steady-state value from quarters 0 to 10, then switches to optimal policy. Third, monetary policy follows the optimal policy throughout. The calibration is given in the "Default Calibration" column of Table 1.*

from their expectations of future price inflation

$$\tilde{\mathbb{E}}_t(w_{t+k}) = \tilde{\mathbb{E}}_t(\omega_{t+k}) + \sum_{i=1}^{k} \tilde{\mathbb{E}}_t(\pi^p_{t+i}) + p_t. \tag{46}$$

Symmetrically, unions still need to form expectations on future wage inflation in order to expect their competitors' future wages. But their expectations of future prices are then

$$\tilde{\mathbb{E}}_t(p_{t+k}) = -\tilde{\mathbb{E}}_t(\omega_{t+k}) + \sum_{i=1}^{k} \tilde{\mathbb{E}}_t(\pi^w_{t+i}) + w_t. \tag{47}$$

Away from rational expectations, this is not equivalent to forming expectations directly on nominal wages. Both assumptions have been used in the literature. Assumption (38) is used for instance in Lorenzoni and Werning (2023b). Assumption (46) is typical in studies that assume nominal wage flexibility, for instance Preston (2005). Indeed, there it is standard to assume that firms understand the equilibrium dependence of the future real wage on future output, and that they learn future output.

While both assumptions produce slightly different dynamics, they yield the same normative recommendations. Figure 7 represents the ranking of the different policies (26) under the adaptive expectations variant. Once again, for non-markup supply shocks, optimal policy is very close to stabilizing the output gap. Details on the model under this adaptive expectations variant are given in Appendix I.

# 4 Real Wage Rigidity and Real Wage Catch-Up

This section introduces a feature distinct from adaptive expectations and de-anchoring risks: real wage rigidity. It shows that it rationalizes central banks' supply shock heuristic. It does so even when assuming rational expectations so that expectations never de-anchor.

## 4.1 Calvo Staggered Real Wage Setting

I model real wage rigidity in a way that is a direct parallel to nominal wage rigidity in the standard model. The modeling approach makes it possible to pinpoint how shifting from

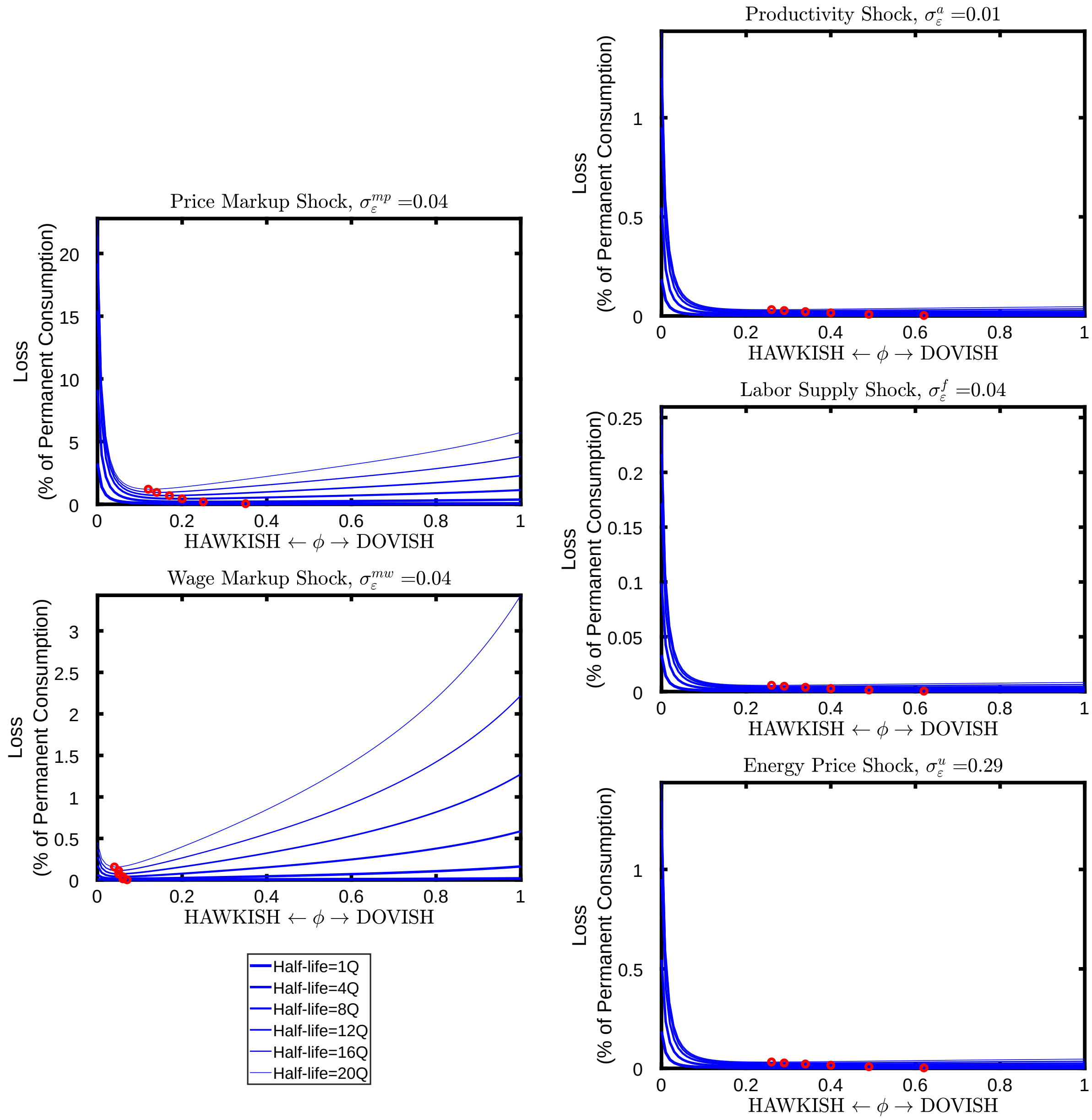



Figure 7: Loss Function under Adaptive Expectations Variant

*Note: For each type of supply shock, the figure plots the loss function of the central bank* (20) *as a function of the weight* $\phi$ *on the output gap in the objective* (26) *of the central bank, under the assumption that the economy is hit by this one type of shock only. It does so for different levels of persistence of the shock, captured by the half-life of the AR(1) process. On each curve, the red dot corresponds to the minimum of the curve, that is the optimal policy within the class of policies* (26)*. The calibration is given in the "Default Calibration" column of Table 1.*

nominal to real wage rigidity changes monetary policy trade-offs. The assumption can be called Calvo staggered *real* wage setting. Unions reset *real* wages with a probability $1-\mu^w$ every period. During the spell of a real wage, nominal wages are automatically indexed to inflation every period so that the real wage remains constant. It can be interpreted as capturing explicit or implicit cost-of-living adjustments in wages (COLA), whereby nominal wages catch up with prices when inflation would otherwise erode real wages.

Optimization under these constraints implies that, when the union resets its *real* wage, it resets it to the weighted average of the future real wage it would reset under flexible wages. The wage-setting equation (14) is replaced by

$$\omega_t^* = (1-\beta\mu^w)\sum_{k=0}^{\infty}(\beta\mu^w)^k\tilde{\mathbb{E}}_t\left(\zeta^w\left(mrs_{t+k}+m_{t+k}^w\right)+(1-\zeta^w)\omega_{t+k}\right), \tag{48}$$

while the equation (18) is now replaced by the following equation linking the resetting wage to the rate of change in the real wage

$$\omega_t - \omega_{t-1} = \frac{1-\mu^w}{\mu^w}(\omega_t^* - \omega_t). \tag{49}$$

Under rational expectations, equations (48) and (49) imply the new (real) wage Phillips curve

$$\omega_t - \omega_{t-1} = \kappa_c^w(\omega_t^e - \omega_t + m_t^w) + \kappa_y^w x_t + \beta\mathbb{E}_t(\omega_{t+1}-\omega_t). \tag{50}$$

The price Phillips curve is still (27).

Shifting from nominal to real wage rigidity makes changes to the central bank's loss function, since the indexation of nominal wages on inflation implies that wage inflation does not necessarily create wage dispersion. Appendix B shows that the microfounded loss function (20) is now

$$\mathcal{L} = \frac{1}{2}(1-\beta)\mathbb{E}_0\sum_{t=0}^{\infty}\beta^t\left[\lambda_x(x_t)^2 + \lambda_p(\pi_t^p)^2 + \lambda_w(\pi_t^w - \pi_t^p)^2\right]. \tag{51}$$

Wage dispersion is now related to changes in the *real wage*, $\Delta_t = \pi_t^w - \pi_t^p$.

## 4.2 Should the Central Bank Be Dovish or Hawkish?

How does real wage rigidity change the desirability of stabilizing price inflation versus the output gap? Figure 8 represents the ranking of the different policies (26) as in Figure 1, but now with real wage rigidity (and still rational expectations). This time, the model can rationalize central banks' supply shock heuristic for productivity, labor supply, and energy price shocks. Optimal monetary policy is very close to stabilizing the output gap when the shock is transitory, but stabilizing the output gap becomes more and more costly as the shock becomes more persistent. As a result, optimal policy becomes hawkish for persistent shocks.

Figure 8 is plotted under the calibration of the frequency $\mu^w$ of wage changes (and everything else) in the default calibration of Table 1: 0.8, or about every 5 quarters. This is a typical calibration for the frequency of changes in *nominal* wages. The frequency of *real* wage changes has no reason to be the same however. Workers and unions may well take more than five quarters to accept the idea of a real wage change, in which case $\mu^w$ should be set higher. Appendix J replicates Figure 8 under an alternative calibration of $\mu^w = 0.9$, keeping all other parameters constant. The cost of stabilizing the output gap becomes all the stronger, and the case for shifting to a more hawkish stance when shocks are persistent all the stronger as well. Conversely, Figure J.2 replicates the figure under an alternative calibration of $\mu^w = 0.5$. Fully stabilizing the output gap no longer produces as large a loss and is no longer worse than fully stabilizing price inflation.

## 4.3 The Worldly Coincidence Index

To understand why real wage rigidity undermines the benefits of stabilizing the output gap, consider how stabilizing the output gap now affects price and wage inflation. Stabilizing the output gap no longer coincides with stabilizing the Divine Coincidence index (33). Yet a new linear combination of price and wage inflation does. Define

$$\pi_t^{WC} = \left(\frac{\kappa_c^w - \kappa_c^p}{\kappa_c^p + \kappa_c^w}\right)\pi_t^p + \left(\frac{\kappa_c^p}{\kappa_c^p + \kappa_c^w}\right)\pi_t^w. \tag{52}$$

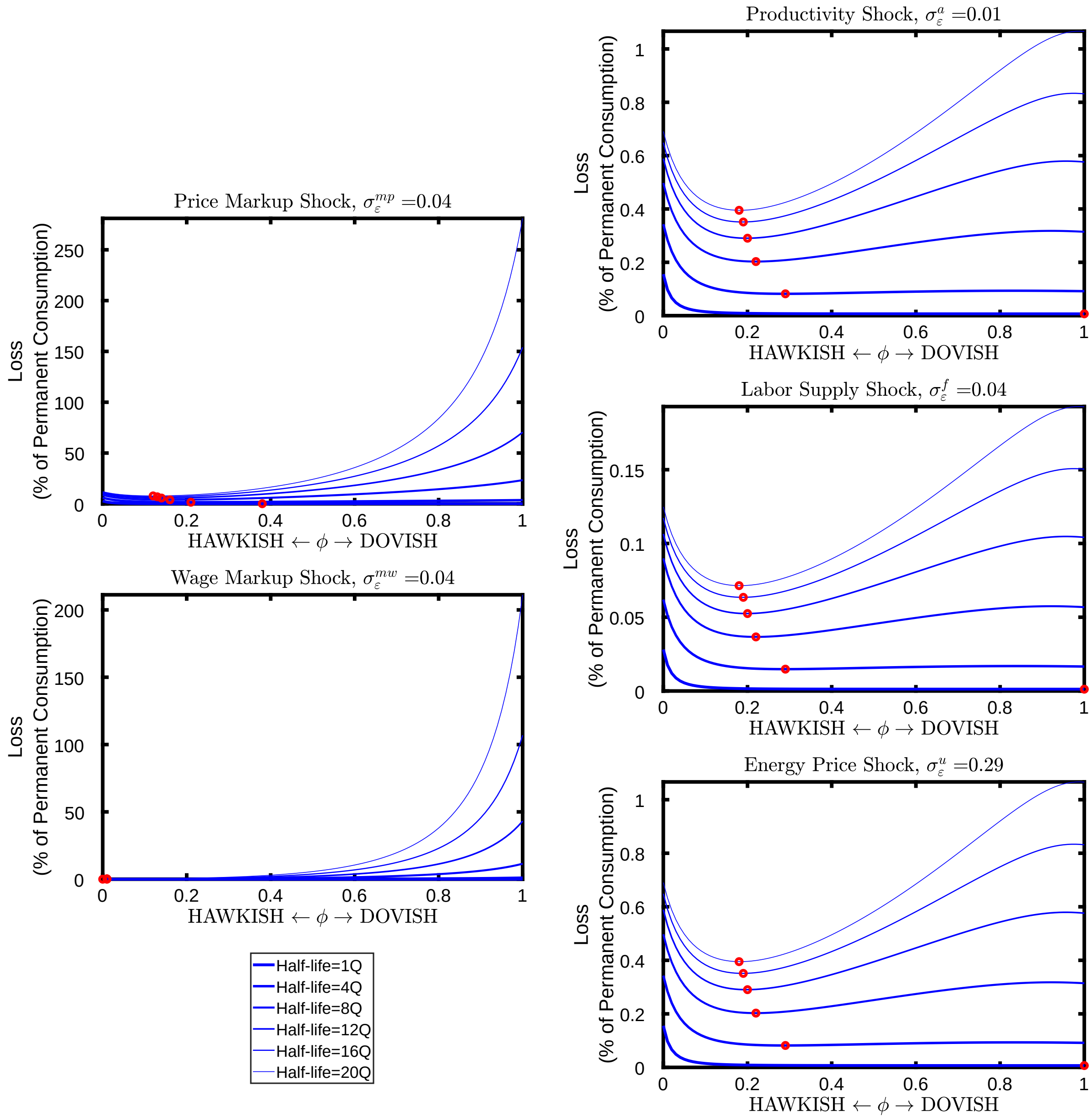



Figure 8: Loss Function under Real Wage Rigidity and Rational Expectations

*Note: For each type of supply shock, the figure plots the loss function of the central bank (51) as a function of the weight $\phi$ on the output gap in the objective (26) of the central bank, under the assumption that the economy is hit by this one type of shock only. It does so for different levels of persistence of the shock, captured by the half-life of the AR(1) process. On each curve, the red dot corresponds to the minimum of the curve, that is the optimal policy within the class of policies (26). The calibration is given in the "Default Calibration" column of Table 1.*

It satisfies

$$\pi_t^{WC} = \left( \frac{\kappa_c^w \kappa_y^p + \kappa_c^p \kappa_y^w}{\kappa_c^w + \kappa_c^p} \right) x_t + \beta \mathbb{E}_t \pi_{t+1}^{WC} + \left( \frac{\kappa_c^p \kappa_c^w}{\kappa_c^w + \kappa_c^p} \right) (m_t^p + m_t^w), \tag{53}$$

so that in the face of productivity, labor supply, or energy price shocks, stabilizing the output gap stabilizes it. While it does coincide with stabilizing the output gap, stabilizing it is far from minimizing the loss function of the central bank. There is nothing divine about the coincidence. I call the weighted average (52) the Worldly Coincidence (WC) index.

Why is stabilizing the Worldly Coincidence index $\pi_t^{WC}$ and the output gap $x_t$ far from optimal? Contrary to the Divine Coincidence index under nominal wage rigidity, stabilizing $\pi_t^{WC}$ does not typically split the change in real wages between price increases and wage decreases. Instead, as soon as $\kappa_c^w < \kappa_c^p$—i.e. when real wages are stickier than nominal prices—stabilizing it causes both prices and wages to move in the same direction—to increase following an inflationary shock. This is therefore far from minimizing the amount of price and wage dispersion. To spread the real-wage adjustment between price increases and wage decreases, a negative output gap is needed. This creates a trade-off between stabilizing the output gap and minimizing the costs of price and wage inflation.

The cost of stabilizing the output gap is all the larger the stickier real wages are. Figure J.2 in Appendix J plots the same graphs as Figure 8 but with $\mu^w = 0.5$ so that $\kappa_c^w > \kappa_c^p$. In this case, stabilizing the output gap does make prices and wages move in opposite directions, and is therefore not too costly a policy. In contrast, Figure J.1 plots the figure with $\mu^w = 0.9$ so that $\kappa_c^w$ is even smaller and stabilizing the output gap is then even more costly.

## 4.4 Combining Real Wage Rigidity and De-anchoring Risks

Importantly, real wage rigidity recovers central banks' supply shock heuristic even under rational expectations, which rules out de-anchoring risks. But what if, on top of real wage rigidity, expectations can de-anchor? Appendix L shows the real wage Phillips curve is now

$$\omega_t - \omega_{t-1} = \kappa_c^w(\omega_t^e - \omega_t + m_t^w) + \kappa_y^w x_t - \beta(1-\mu^w)\zeta^w \omega_t + \frac{\beta(1-\mu^w)}{1-\beta\mu^w}(1-\zeta^w)(\pi_{t-1}^{w*} - \pi_{t-1}^{p*}). \tag{54}$$

The price Phillips curve is still (41).

Figure 9 represents the ranking of the different policies (26) as in Figure 1 but under the joint assumptions of real wage rigidity and adaptive expectations.[21] The model once again recovers central banks' supply shock heuristic. But the figure is overall similar to the case of real wage rigidity and rational expectations. What is driving the need for a hawkish pivot in the face of persistent productivity, labor supply, and energy price shocks is real wage rigidity, not de-anchoring risks.

# Conclusion

Central banks' heuristic on how to respond to supply shocks is often expressed with reference to the concepts of *wage-price spirals* and *second-round effects*: if the supply shock is persistent, a more hawkish stance becomes justified to avoid wage-price spirals and second-round effects. Yet those terms are typically used loosely, bundling together two distinct mechanisms: the risk that inflation expectations de-anchor and the dynamics of real-wage catch-up.[22] The message of this paper is that disentangling the two is important because they have different normative implications. In the face of a persistent supply shock, de-anchoring risks do not by themselves justify a departure from output gap stabilization. Real-wage rigidity does.

[21] Appendix L considers the joint assumption of real wage rigidity and the adaptive expectations variant. Results are very similar.

[22] For instance, in the ECB press conference of July 27, 2023, Lagarde said: *"[If] we look at inflation expectations, if we look at how wages and profit margins are evolving, we are not seeing a second-round effect"* (Lagarde 2023).

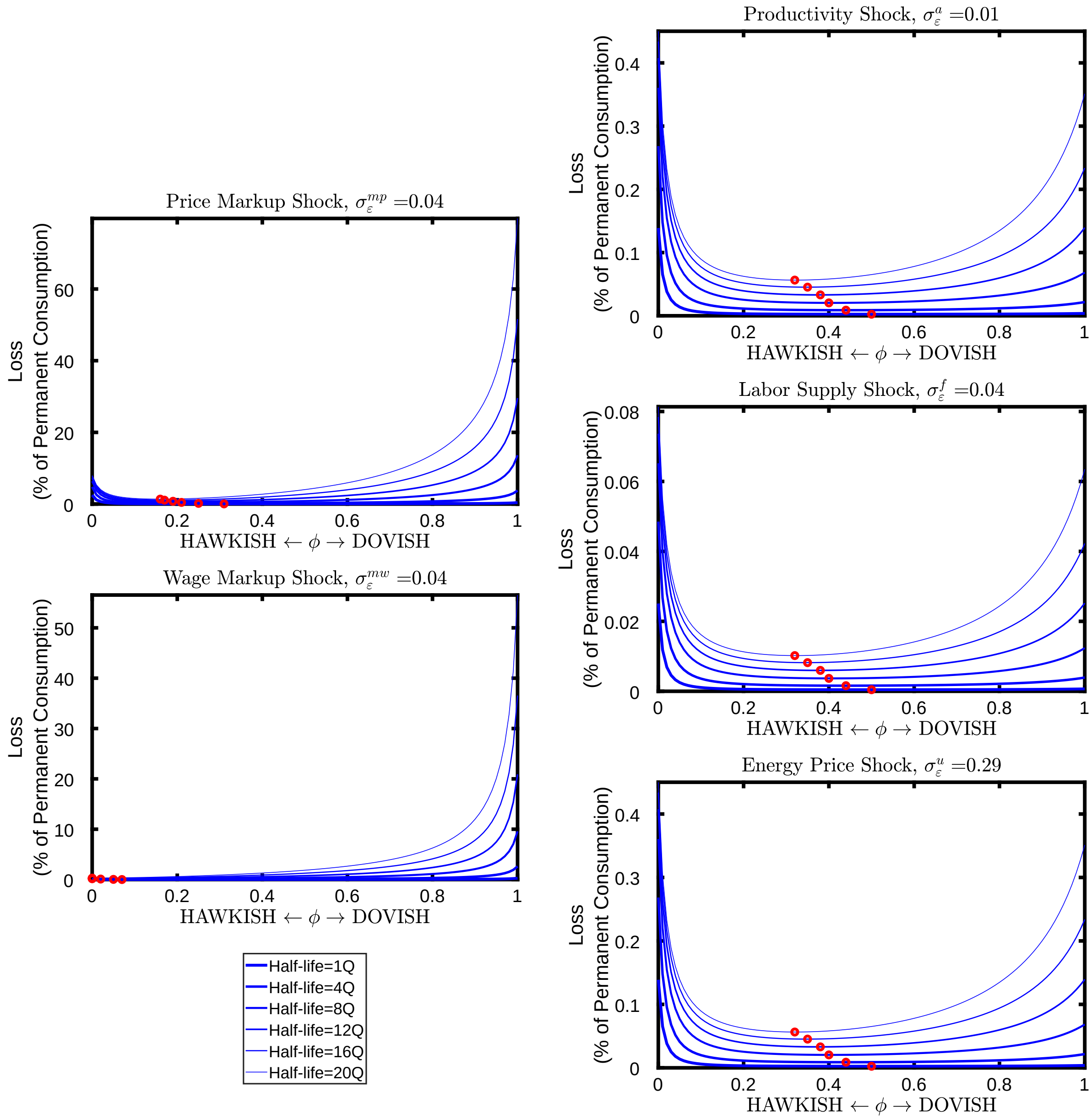



Figure 9: Loss Function under Real Wage Rigidity and Adaptive Expectations

*Note: For each type of supply shock, the figure plots the loss function of the central bank* (51) *as a function of the weight $\phi$ on the output gap in the objective* (26) *of the central bank, under the assumption that the economy is hit by this one type of shock only. It does so for different levels of persistence of the shock, captured by the half-life of the AR(1) process. On each curve, the red dot corresponds to the minimum of the curve, that is the optimal policy within the class of policies* (26)*. The calibration is given in the "Default Calibration" column of Table 1.*

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# A Derivation of Price and Wage Setting

## A.1 Firm $i$'s price-setting

When it does reset its price, firm $i$ resets it taking as given the nominal wage $W_t$, the energy price $P_t^E$, and the demand curve it faces,

$$Z_t^i = \left(\frac{P_t^i}{P_t}\right)^{-\theta_t^p} Z_t. \tag{A.1}$$

Absent price rigidity, firm $i$ would set the price

$$P_t^{i,flex} = \mathcal{M}_t^p \times \frac{W_t}{MPL_t^i}, \tag{A.2}$$

where

$$\mathcal{M}_t^p = \frac{\theta_t^p}{\theta_t^p - 1} \tag{A.3}$$

is the price markup and $MPL_t^i$ is firm $i$'s marginal product of labor.

Moving to log-linearized terms, this gives

$$p_t^{i,flex} = w_t - mpl_t^i + m_t^p, \tag{A.4}$$

where firm $i$'s marginal product of labor can be written, from firm $i$'s cost minimization program,

$$mpl_t^i = \frac{1}{\alpha}a_t - \frac{1-\alpha}{\alpha}z_t^i + \frac{\alpha_E}{\alpha}(w_t - p_t^E), \tag{A.5}$$

where the term in $w_t - p_t^E$ reflects substitution between labor and energy. From equation (5), it is equal to the exogenous $w_t - p_t^E = \upsilon_t$ shock.

Using firm $i$'s demand curve (A.1), equation (A.4) can be rewritten

$$p_t^{i,flex} = \zeta^p(w_t - mpl_t + m_t^p) + (1-\zeta^p)p_t, \tag{A.6}$$

where

$$mpl_t = \frac{1}{\alpha} a_t - \frac{1-\alpha}{\alpha} z_t + \frac{\alpha_E}{\alpha} \upsilon_t \tag{A.7}$$

is the economy-wide marginal productivity of labor given in equation (10), $\theta^p$ is the steady-state value of $\theta_t^p$, and

$$\zeta^p = \frac{1}{1 + \frac{(1-\alpha)\theta^p}{\alpha}}. \tag{A.8}$$

Firm $i$ sets prices under Calvo staggered price-setting. When it does reset, profit-maximization makes it reset to

$$p_t^* = (1 - \beta\mu^p) \sum_{k=0}^{\infty} (\beta\mu^p)^k \tilde{\mathbb{E}}_t \left( p_{t+k}^{i,flex} \right), \tag{A.9}$$

where $\tilde{\mathbb{E}}$ denotes firm $i$'s subjective expectations, on which no further assumption is made for the moment. They may or may not be rational. Plugging in (A.6) gives equation (9) in the main text.

## A.2 Union $j$'s wage-setting

Absent wage rigidity, union $j$ would set the wage

$$W_t^{j,flex} = \mathcal{M}_t^w \times P_t \times MRS_t^j \tag{A.10}$$

where

$$\mathcal{M}_t^w = \theta_t^w / (\theta_t^w - 1) \tag{A.11}$$

is the wage markup and $MRS_t^j$ is the marginal rate of substitution between consumption and supplying labor type $j$.

Moving to log-deviation terms and using the labor demand curve (12), this can be written

$$w_t^{j,flex} = \zeta^w (p_t + mrs_t + m_t^w) + (1 - \zeta^w) w_t \tag{A.12}$$

where

$$mrs_t = \psi n_t + \sigma c_t + f_t, \tag{A.13}$$

is the economy-wide marginal rate of substitution, $\theta^w$ is the steady-state value of $\theta_t^w$, and

$$\zeta^w = \frac{1}{1 + \psi\theta^w}. \tag{A.14}$$

Union $j$ sets wages under Calvo staggered wage-setting. Each period, it faces a probability $1 - \mu^w$ of being able to reset its wage. When it does reset its wage, it resets it to

$$w_t^* = (1 - \beta\mu^w)\sum_{k=0}^{\infty}(\beta\mu^w)^k \tilde{\mathbb{E}}_t\left(w_{t+k}^{j,flex}\right), \tag{A.15}$$

where $\tilde{\mathbb{E}}$ denotes union $j$'s subjective expectations, on which we make no further assumption for the moment. They may or may not be rational. Plugging in the expression for the flexible wage (A.12) gives equation (14) for the resetting wage.

# B Derivation of the Loss Function

Step 1: Second-Order Approximation to the Period Utility

The preferences of the representative household are

$$\mathcal{U} = \mathbb{E}_0 \sum_{t=0}^{\infty}(1 - \beta)\beta^t U_t, \tag{B.1}$$

where

$$U_t = \frac{C_t^{1-\sigma}}{1 - \sigma} - \mathcal{F}_t \int_j \frac{(N_t^j)^{1+\psi}}{1 + \psi} dj. \tag{B.2}$$

A second-order approximation to $U$ gives

$$dU = \left( (u'_C C) \left( \frac{dC}{C} \right) + \frac{u''_{CC} C^2}{2} \left( \frac{dC}{C} \right)^2 \right) \tag{B.3}$$
$$- \int_j \left( (v'_N N) \left( \frac{dN^j}{N} \right) + (v'_N N) \left( \frac{dN^j}{N} \right) f + \frac{v''_{NN} N^2}{2} \left( \frac{dN^j}{N} \right)^2 \right) dj.$$

Using the fact that at second order

$$\frac{dX}{X} = x + \frac{1}{2} x^2, \tag{B.4}$$

and that $u''_{CC} C^2 = -\sigma u'_C C$, $v''_{NN} N^2 = \psi v'_N N$, this can be rewritten as

$$dU = (u'_C C) \left( c + \frac{1-\sigma}{2} c^2 \right) - (v'_N N) \int_j \left( n^j + n^j f + \frac{1+\psi}{2} (n^j)^2 \right) dj. \tag{B.5}$$

Using the fact that the steady state is efficient,

$$u'_C C = \frac{v'_N N}{\alpha}, \tag{B.6}$$

where $\alpha = \alpha_N + \alpha_E$, and dividing by $u'_C C$ to get the consumption-equivalent period loss gives

$$L = \frac{-dU}{u'_C C} = -\left( c + \frac{1-\sigma}{2} c^2 \right) + \alpha \int_j \left( n^j + n^j f + \frac{1+\psi}{2} (n^j)^2 \right) dj. \tag{B.7}$$

**Inefficiencies from wage dispersion**

Since at second order

$$\int_j n^j + \frac{1+\psi}{2} \int_j (n^j)^2 = n + \frac{1+\psi}{2} n^2 + \frac{\theta^w}{2\zeta^w} \mathbb{V}ar^j(w^j), \tag{B.8}$$
$$\int_j n^j f = nf, \tag{B.9}$$

the loss can be rewritten as

$$L = -\left(c + \frac{1-\sigma}{2}c^2\right) + \alpha\left(n + nf + \frac{1+\psi}{2}n^2 + \frac{\theta^w}{2\zeta^w}\mathbb{V}ar^j(w^j)\right). \tag{B.10}$$

**Inefficiencies from price dispersion** Since at second order,

$$n = \frac{1}{\alpha}\left(z - a - \alpha_E \upsilon + \frac{1}{2}\frac{\theta^p}{\zeta^p}\mathbb{V}ar^i(p^i)\right), \tag{B.11}$$

$$nf = \frac{1}{\alpha}(z - a - \alpha_E \upsilon)f, \tag{B.12}$$

$$n^2 = \frac{1}{\alpha^2}(z - a - \alpha_E \upsilon)^2. \tag{B.13}$$

Therefore,

$$\begin{aligned} L = &-\left(c + \frac{1-\sigma}{2}c^2\right) \\ &+ \left(z - a - \alpha_E \upsilon + (z - a - \alpha_E \upsilon)f + \frac{1+\psi}{2\alpha}(z - a - \alpha_E \upsilon)^2 + \frac{1}{2}\frac{\theta^p}{\zeta^p}\mathbb{V}ar^i(p^i) + \frac{\alpha\theta^w}{2\zeta^w}\mathbb{V}ar^j(w^j)\right). \end{aligned} \tag{B.14}$$

**Market-clearing**

Imposing market clearing $c = z$,

$$L = -a - \alpha_E \upsilon + (z - a - \alpha_E \upsilon)f + \frac{\sigma-1}{2}z^2 + \frac{1+\psi}{2\alpha}(z - a - \alpha_E \upsilon)^2 + \frac{1}{2}\frac{\theta^p}{\zeta^p}\mathbb{V}ar^i(p^i) + \frac{\alpha\theta^w}{2\zeta^w}\mathbb{V}ar^j(w^j). \tag{B.15}$$

**Difference to efficient allocation**

Define the output gap relative to the efficient allocation as

$$x_t \equiv z_t - z_t^e. \tag{B.16}$$

The efficient allocation is characterized by $mrs_t = mpl_t$. Since

$$mrs_t = \psi n_t + \sigma z_t + f_t, \tag{B.17}$$

$$mpl_t = \frac{1}{\alpha}a_t - \frac{1-\alpha}{\alpha}z_t + \frac{\alpha_E}{\alpha}\upsilon_t, \tag{B.18}$$

$$n_t = \frac{1}{\alpha}(z_t - a_t - \alpha_E \upsilon_t), \tag{B.19}$$

the efficient level of output is

$$z_t^e = \frac{\frac{1+\psi}{\alpha}(a_t + \alpha_E \upsilon_t) - f_t}{\frac{1-\alpha+\psi}{\alpha} + \sigma}. \tag{B.20}$$

The associated efficient wage that decentralizes the efficient allocation under perfect competition and absent nominal rigidities, $\omega_t^e = mpl_t^e = mrs_t^e$, is

$$\omega_t^e = \frac{\frac{\sigma+\psi}{\alpha}(a_t + \alpha_E \upsilon_t) + \frac{1-\alpha}{\alpha} f_t}{\frac{1-\alpha+\psi}{\alpha} + \sigma}. \tag{B.21}$$

Taking the difference between the loss under the actual allocation and the loss under the efficient allocation gives

$$\begin{aligned} L - L^e = &\left( f + (\sigma - 1) z^e + \frac{1+\psi}{\alpha}(z^e - a - \alpha_E \upsilon) \right) x \\ &+ \frac{1}{2}\left[ \left( \sigma + \frac{1-\alpha+\psi}{\alpha} \right) x^2 + \frac{\theta^p}{\zeta^p} \mathbb{V}ar^i(p^i) + \frac{\alpha\theta^w}{\zeta^w} \mathbb{V}ar^j(w^j) \right]. \end{aligned} \tag{B.22}$$

The first term is zero because the efficient allocation equates the marginal rate of substitution and the marginal product of labor. Since $L^e$ is independent of policy, it can be dropped. Thus the period loss can be written, up to terms independent of policy, as

$$L = \frac{1}{2}\left[ \left( \sigma + \frac{1-\alpha+\psi}{\alpha} \right) x^2 + \frac{\theta^p}{\zeta^p} \mathbb{V}ar^i(p^i) + \frac{\alpha\theta^w}{\zeta^w} \mathbb{V}ar^j(w^j) \right]. \tag{B.23}$$

Hence the central bank's intertemporal loss function is equal, up to a second-order approximation, to

$$\mathcal{L} = (1-\beta)\frac{1}{2}\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[ \left( \sigma + \frac{1-\alpha+\psi}{\alpha} \right) x_t^2 + \frac{\theta^p}{\zeta^p} \mathbb{V}ar_t^i(p_t^i) + \frac{\alpha\theta^w}{\zeta^w} \mathbb{V}ar_t^j(w_t^j) \right]. \tag{B.24}$$

This first step makes no assumptions beyond those regarding preferences, goods market clearing, and the assumption that the steady state is efficient.

Step 2: Expression of Price Dispersion

Under Calvo staggered price setting, $\sum \beta^t \mathbb{V}ar^i(p_t^i)$ can be rewritten as a function of the inflation path. The distribution of prices $p_t^i$ at $t$ is a mixture of a Dirac mass at $p_t^*$ with probability $1-\mu^p$, and the past distribution of prices at $t-1$ with probability $\mu^p$. Hence,

$$\mathbb{V}ar_t^i(p_t^i) = (1-\mu^p)(p_t^* - p_t)^2 + \mu^p \left( \mathbb{V}ar_{t-1}^i(p_{t-1}^i) + (\pi_t^p)^2 \right). \tag{B.25}$$

Using

$$\pi_t^p = \frac{1-\mu^p}{\mu^p}(p_t^* - p_t), \tag{B.26}$$

it follows that

$$\mathbb{V}ar_t^i(p_t^i) = \frac{\mu^p}{1-\mu^p}(\pi_t^p)^2 + \mu^p \mathbb{V}ar_{t-1}^i(p_{t-1}^i). \tag{B.27}$$

Iterating backward and ignoring the initial condition, which is independent of policy,

$$\sum_{t=0}^{\infty} \beta^t \mathbb{V}ar_t^i(p_t^i) = \frac{\mu^p}{(1-\mu^p)(1-\beta\mu^p)} \sum_{t=0}^{\infty} \beta^t (\pi_t^p)^2. \tag{B.28}$$

This second step relies on Calvo staggered prices, but makes no assumption on private-sector expectations.

Step 3: Expression of Wage Dispersion

Under Calvo nominal wage setting, following the same steps as for price dispersion gives

$$\sum_{t=0}^{\infty} \beta^t \mathbb{V}ar_t^j(w_t^j) = \frac{\mu^w}{(1-\mu^w)(1-\beta\mu^w)} \sum_{t=0}^{\infty} \beta^t (\pi_t^w)^2. \tag{B.29}$$

Injecting (B.28) and (B.29) into (B.23) gives

$$\mathcal{L} = (1-\beta)\frac{1}{2}\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\chi x_t^2 + \lambda_p (\pi_t^p)^2 + \lambda_w (\pi_t^w)^2\right], \tag{B.30}$$

where

$$\chi = \sigma + \frac{1-\alpha+\psi}{\alpha}, \tag{B.31}$$

$$\lambda_p = \frac{\theta^p}{\zeta^p} \frac{\mu^p}{(1-\mu^p)(1-\beta\mu^p)}, \tag{B.32}$$

$$\lambda_w = \frac{\alpha\theta^w}{\zeta^w} \frac{\mu^w}{(1-\mu^w)(1-\beta\mu^w)}. \tag{B.33}$$

Under real wage rigidity instead of nominal wage rigidity, equations (B.23) and (B.28) are still valid, while (B.29) is replaced by

$$\sum_{t=0}^{\infty} \beta^t \mathbb{V}ar^j(w_t^j) = \frac{\mu^w}{(1-\mu^w)(1-\beta\mu^w)} \sum_{t=0}^{\infty} \beta^t (\pi_t^w - \pi_t^p)^2. \tag{B.34}$$

Injecting (B.28) and (B.34) into (B.23) gives (51).

# C Derivation of the Phillips Curves under Rational Expectations

Under rational expectations, the price and wage-setting equations (9)-(14) can be written recursively as

$$p_t^* = (1-\beta\mu^p)\left(\zeta^p\left(\omega_t - mpl_t + m_t^p\right) + p_t\right) + (\beta\mu^p)\mathbb{E}_t p_{t+1}^*, \tag{C.1}$$

$$w_t^* = (1-\beta\mu^w)\left(\zeta^w\left(mrs_t - \omega_t + m_t^w\right) + w_t\right) + (\beta\mu^w)\mathbb{E}_t w_{t+1}^*. \tag{C.2}$$

Using the fact that

$$\pi_t^p = \frac{1-\mu^p}{\mu^p}(p_t^* - p_t), \tag{C.3}$$

$$\pi_t^w = \frac{1-\mu^w}{\mu^w}(w_t^* - w_t), \tag{C.4}$$

it can be rewritten as the price and wage NKPC

$$\pi_t^p = \kappa_c^p\Big(\omega_t - mpl_t + m_t^p\Big) + \beta\mathbb{E}_t\pi_{t+1}^p, \tag{C.5}$$

$$\pi_t^w = \kappa_c^w\Big(mrs_t - \omega_t + m_t^w\Big) + \beta\mathbb{E}_t\pi_{t+1}^w, \tag{C.6}$$

where

$$\omega_t = w_t - p_t \tag{C.7}$$

denotes the real wage. The NKPC (C.5) and (C.6) can be rewritten as (27) and (28) where the efficient level of output corresponds to $mrs_t = mpl_t$ and is given by equation (B.20), and the efficient level of real wage $\omega_t^e$ (i.e. the real wage that would obtain under flexible prices and wages and perfect competition) is given by equation (B.21).

# D Shock Normalization

This appendix describes the normalization of the standard deviations of the five supply shocks used in all figures. The volatility of each supply shock's innovation is set such that the (absolute value of) the effect on output of a one-standard-deviation innovation to the shock in a rational expectations flexible-price and flexible-wage economy is $q$. We set $q = 1\%$.

The allocation that would obtain in the rational expectations flexible-price and flexible-wage economy can be easily characterized. Labor supply and labor demand give

$$\omega_t = mpl_t - m_t^p, \tag{D.1}$$

$$\omega_t = mrs_t + m_t^w, \tag{D.2}$$

Table 2: Calibration of the Shocks' Standard Deviations

| Shock | Standard deviation |
|---|---|
| Productivity | $\sigma_\varepsilon^a = 1\%$ |
| Energy price | $\sigma_\varepsilon^\upsilon = 28.6\%$ |
| Labor supply | $\sigma_\varepsilon^f = 4.3\%$ |
| Price markup | $\sigma_\varepsilon^{m^p} = 4.3\%$ |
| Wage markup | $\sigma_\varepsilon^{m^w} = 4.3\%$ |

*Note:* The standard deviations are calibrated such that a one-standard-deviation innovation to each shock has an effect on output of 1% (in absolute value) in the flexible-price/flexible-wage economy under rational expectations, for the main calibration in Table 1.

so that

$$mrs_t - mpl_t + m_t^p + m_t^w = 0. \tag{D.3}$$

Using the equilibrium expressions (10) and (15) for $mrs_t$ and $mpl_t$ gives

$$z_t^n = \frac{\frac{1+\psi}{\alpha}(a_t + \alpha_E \upsilon_t) - f_t - m_t^p - m_t^w}{D}, \tag{D.4}$$

where

$$D = \sigma + \frac{1 - \alpha + \psi}{\alpha}. \tag{D.5}$$

The shocks' standard deviations are therefore calibrated to

$$\sigma_\varepsilon^a = q\frac{\alpha D}{1+\psi}, \tag{D.6}$$

$$\sigma_\varepsilon^\upsilon = q\frac{\alpha D}{\alpha_E(1+\psi)}, \tag{D.7}$$

$$\sigma_\varepsilon^f = qD, \tag{D.8}$$

$$\sigma_\varepsilon^{m^p} = qD, \tag{D.9}$$

$$\sigma_\varepsilon^{m^w} = qD. \tag{D.10}$$

Table 2 provides the resulting values for the main calibration in Table 1.

# E Optimal Policy Under Rational Expectations

Let $\eta_t^1, \eta_t^2, \eta_t^3$ be the Lagrange multipliers on the constraints (27), (28) and (19). The first-order conditions of the central bank's program with respect to $x_t$, $\pi_t^p$, $\pi_t^w$ and $\omega$ are

$$\lambda_x x_t + \kappa_y^p \eta_t^1 + \kappa_y^w \eta_t^2 = 0, \tag{E.1}$$

$$\lambda_p \pi_t^p - \eta_t^1 + \eta_{t-1}^1 + \eta_t^3 = 0, \tag{E.2}$$

$$\lambda_w \pi_t^w - \eta_t^2 + \eta_{t-1}^2 - \eta_t^3 = 0, \tag{E.3}$$

$$\kappa_c^p \eta_t^1 - \kappa_c^w \eta_t^2 + \eta_t^3 - \beta \mathbb{E}_t \eta_{t+1}^3 = 0. \tag{E.4}$$

The optimal policy that abstracts from the costs of wage dispersion is characterized in the same way, except that $\lambda_w = 0$ in equation (E.3).

# F Derivation of the Phillips Curves under Adaptive Expectations

We derive the price Phillips curve under adaptive expectations (41). The wage Phillips curve then follows the same steps. Subtracting $p_t$ (which is perfectly observed by firms) from the expression of the resetting price (9) and using the fact that time-$t$ variables are perfectly observed by the firm gives

$$\begin{aligned} p_t^* - p_t = {} & (1-\beta\mu^p)\zeta^p(\omega_t - mpl_t + m_t^p) \\ & + (1-\beta\mu^p)\sum_{k=1}^{\infty}(\beta\mu^p)^k \tilde{E}_t\left(\zeta^p\left(w_{t+k} - p_t - mpl_{t+k} + m_{t+k}^p\right) + (1-\zeta^p)(p_{t+k} - p_t)\right), \end{aligned} \tag{F.1}$$

Using the assumptions on expectations formation of future prices and nominal wages (39) and (40) it can be rewritten

$$\begin{aligned}p_t^* - p_t &= (1-\beta\mu^p)\zeta^p(\omega_t - mpl_t + m_t^p) \\ &\quad + (1-\beta\mu^p)\zeta^p\sum_{k=1}^{\infty}(\beta\mu^p)^k\tilde{E}_t\Big(\omega_t - mpl_{t+k} + m_{t+k}^p\Big) \\ &\quad + \sum_{k=1}^{\infty}(\beta\mu^p)^k\tilde{E}_t\Big(\zeta^p\pi_{t+k}^w + (1-\zeta^p)\pi_{t+k}^p\Big). \end{aligned} \tag{F.2}$$

Assuming expectations at all horizons are the same,

$$\begin{aligned}p_t^* - p_t &= (1-\beta\mu^p)\zeta^p(\omega_t - mpl_t + m_t^p) \\ &\quad + \zeta^p(\beta\mu^p)\Big(\omega_t - mpl_{t-1}^* + m_{t-1}^{p*}\Big) \\ &\quad + \frac{\beta\mu^p}{1-\beta\mu^p}\Big(\zeta^p\pi_{t-1}^{w*} + (1-\zeta^p)\pi_{t-1}^{p*}\Big). \end{aligned} \tag{F.3}$$

Using (C.3), it gives

$$\begin{aligned}\pi_t^p &= \kappa_c^p\Big(\omega_t - \omega_t^e + m_t^p\Big) + \kappa_y^p x_t + \zeta^p\beta(1-\mu^p)\Big(\omega_t - mpl_{t-1}^* + m_{t-1}^{p*}\Big) \\ &\quad + \frac{\beta(1-\mu^p)}{1-\beta\mu^p}\Big(\zeta^p\pi_{t-1}^{w*} + (1-\zeta^p)\pi_{t-1}^{p*}\Big). \end{aligned} \tag{F.4}$$

Under the assumption that expectations of $z$, $a$, $\upsilon$, $m^p$—and so $mpl$—are constant at their steady-state values, this gives equation (41). Similarly for wage-setting

$$\begin{aligned}\pi_t^w &= \kappa_c^w\Big(\omega_t^e - \omega_t + m_t^w\Big) + \kappa_y^w x_t + \zeta^w\beta(1-\mu^w)\Big(mrs_{t-1}^* - \omega_t + m_{t-1}^{w*}\Big) \\ &\quad + \frac{\beta(1-\mu^w)}{1-\beta\mu^w}\Big(\zeta^w\pi_{t-1}^{p*} + (1-\zeta^w)\pi_{t-1}^{w*}\Big), \end{aligned} \tag{F.5}$$

which reduces to (42) under the assumption that $c$, $n$, $f$, $m^w$—and so $mrs$—are constant at their steady-state values.

# G Optimal Policy Under Adaptive Expectations

The central bank seeks to minimize (20) subject to (41), (42), (19), (39) and (40). Let $\eta_t^1, \eta_t^2, \eta_t^3, \eta_t^4, \eta_t^5$ be the Lagrange multipliers on the five constraints. The first-order conditions of the central bank's program with respect to $x_t$, $\pi_t^p$, $\pi_t^w$; $\omega_t$, $\pi_t^{p*}$ and $\pi_t^{w*}$ are

$$\lambda_x x_t + \kappa_y^p \eta_t^1 + \kappa_y^w \eta_t^2 = 0, \tag{G.1}$$

$$\lambda_p \pi_t^p - \eta_t^1 + \gamma \eta_t^4 + \eta_t^3 = 0, \tag{G.2}$$

$$\lambda_w \pi_t^w - \eta_t^2 + \gamma \eta_t^5 - \eta_t^3 = 0, \tag{G.3}$$

$$(\kappa_c^p + \beta(1-\mu^p)\zeta^p)\eta_t^1 - (\kappa_c^w + \beta(1-\mu^w)\zeta^w)\eta_t^2 + \eta_t^3 - \beta \mathbb{E}_t \eta_{t+1}^3 = 0, \tag{G.4}$$

$$\frac{\beta^2(1-\mu^p)}{1-\beta\mu^p}(1-\zeta^p)\mathbb{E}_t \eta_{t+1}^1 + \frac{\beta^2(1-\mu^w)}{1-\beta\mu^w}\zeta^w \mathbb{E}_t \eta_{t+1}^2 - \eta_t^4 + \beta(1-\gamma)\mathbb{E}_t \eta_{t+1}^4 = 0, \tag{G.5}$$

$$\frac{\beta^2(1-\mu^p)}{1-\beta\mu^p}\zeta^p \mathbb{E}_t \eta_{t+1}^1 + \frac{\beta^2(1-\mu^w)}{1-\beta\mu^w}(1-\zeta^w)\mathbb{E}_t \eta_{t+1}^2 - \eta_t^5 + \beta(1-\gamma)\mathbb{E}_t \eta_{t+1}^5 = 0. \tag{G.6}$$

The optimal policy that abstracts from the costs of wage dispersion is characterized in the same way, except that $\lambda_w = 0$ in equation (G.3).

# H Optimal Policy After Overly Accommodative Policy under Rational Expectations

Figure H.1 plots the equivalent of Figure 6 under rational expectations. A past policy mistake—e.g. too accommodative policy in the past—has little effect on optimal policy today. It still approximately consists in stabilizing the output gap.

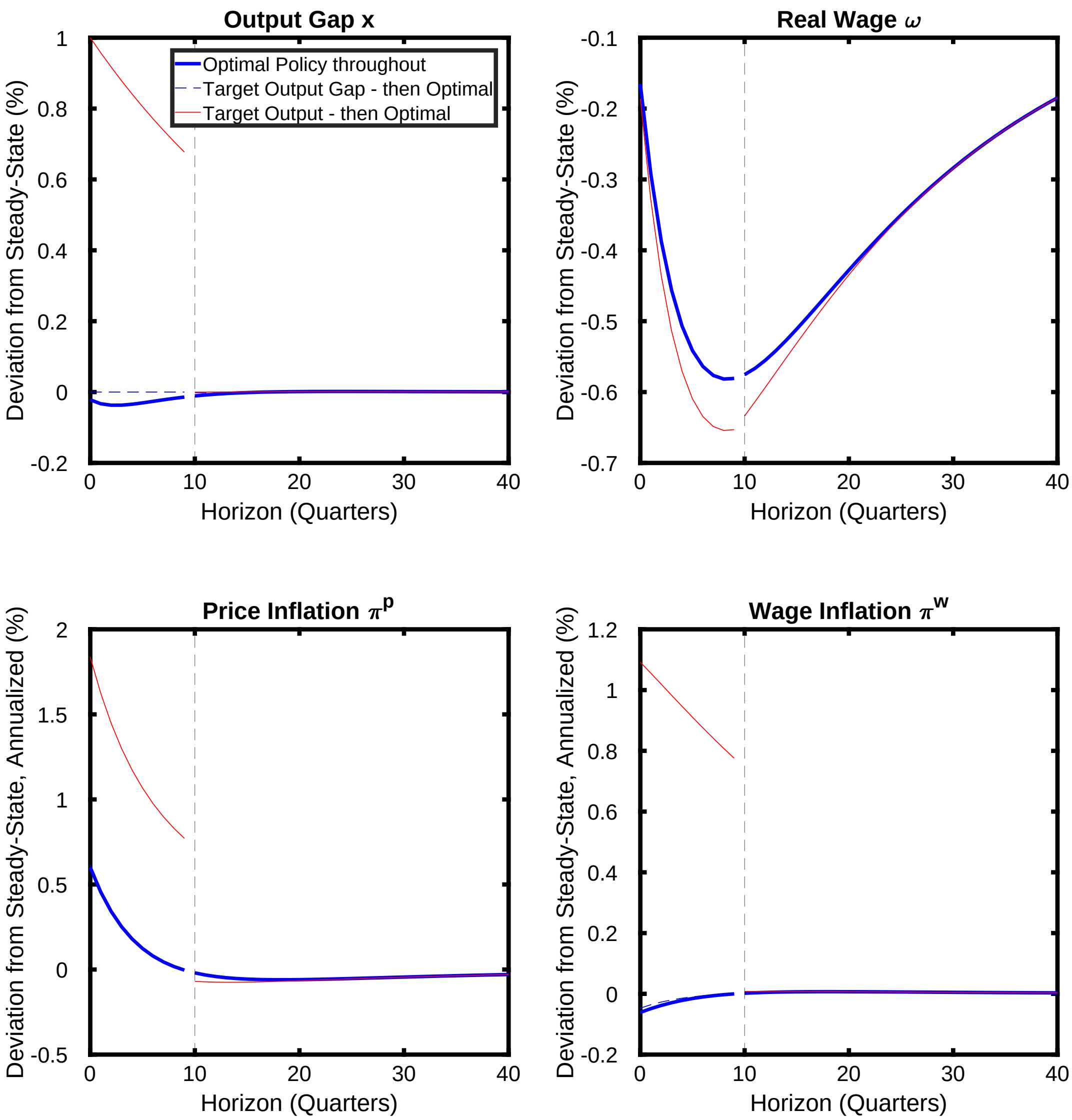


Figure H.1: Optimal Policy After Overly Accommodative Policy, Rational Expectations

*Note: The figure plots the response of the output gap, the real wage, price inflation and wage inflation to a persistent increase in the price of energy with a half-life of 16 quarters, under three scenarios. First, monetary policy keeps the output gap constant at zero from quarters 0 to 10, then switches to fully optimal policy. Second, monetary policy keeps output constant at its steady-state value from quarters 0 to 10, then switches to optimal policy. Third, monetary policy follows the optimal policy throughout. The calibration is given in the "Default Calibration" column of Table 1.*

# I Adaptive Expectations Variant

First, derive the price and wage Phillips curves. Start with the price Phillips curve. Subtracting $p_t$ (which is perfectly observed by firms) from the expression of the resetting price (9) gives

$$p_t^* - p_t = (1-\beta\mu^p)\zeta^p(\omega_t - mpl_t + m_t^p) + (1-\beta\mu^p)\sum_{k=1}^{\infty}(\beta\mu^p)^k \tilde{E}_t\left(\zeta^p\left(w_{t+k} - p_t - mpl_{t+k} + m_{t+k}^p\right) + \frac{\zeta^p(1-\alpha)\theta^p}{\alpha}(p_{t+k}-p_t)\right). \tag{I.1}$$

Since the firm forms expectations directly on the real wage (46), we can write

$$\tilde{E}_t(w_{t+k} - p_t) = \tilde{E}_t(\omega_{t+k}) + \tilde{E}_t\left(\sum_{i=1}^{k}\pi_{t+i}^p\right). \tag{I.2}$$

Equation (I.1) can then be rewritten

$$\begin{aligned} p_t^* - p_t = {} & (1-\beta\mu^p)\zeta^p(\omega_t - mpl_t + m_t^p) \\ & + (1-\beta\mu^p)\zeta^p\sum_{k=1}^{\infty}(\beta\mu^p)^k \tilde{E}_t\left(\omega_{t+k} - mpl_{t+k} + m_{t+k}^p\right) \\ & + \sum_{k=1}^{\infty}(\beta\mu^p)^k \tilde{E}_t \pi_{t+k}^p. \end{aligned} \tag{I.3}$$

Assuming expectations at all horizons are the same,

$$\begin{aligned} p_t^* - p_t = {} & (1-\beta\mu^p)\zeta^p(\omega_t - mpl_t + m_t^p) \\ & + \zeta^p(\beta\mu^p)\left(\omega_{t-1}^* - mpl_{t-1}^* + m_{t-1}^{p*}\right) \\ & + \frac{\beta\mu^p}{1-\beta\mu^p}\pi_{t-1}^{p*}. \end{aligned} \tag{I.4}$$

Using (C.3) and under the assumption that expectations of $z$, $a$, $v$, $m^p$ are constant at their steady-state values, it gives

$$\pi_t^p = \kappa_c^p \left( \omega_t - \omega_t^e + m_t^p \right) + \kappa_y^p x_t + \zeta^p \beta (1-\mu^p) \omega_{t-1}^* + \frac{\beta(1-\mu^p)}{1-\beta\mu^p} \left( \pi_{t-1}^{p*} \right). \tag{I.5}$$

Following the same steps, the wage Phillips curve is

$$\pi_t^w = \kappa_c^w \left( \omega_t^e - \omega_t + m_t^w \right) + \kappa_y^w x_t - \zeta^w \beta (1-\mu^w) \omega_{t-1}^* + \frac{\beta(1-\mu^w)}{1-\beta\mu^w} \left( \pi_{t-1}^{w*} \right). \tag{I.6}$$

Consider now optimal policy. The central bank seeks to minimize (20) subject to (I.5), (I.6), (19), (39), (40) and (45). Let $\eta_t^1, \eta_t^2, \eta_t^3, \eta_t^4, \eta_t^5$, $\eta_t^6$ be the Lagrange multipliers on the six constraints. The first-order conditions of the central bank's program with respect to $x_t$, $\pi_t^p$, $\pi_t^w$; $\omega_t$, $\pi_t^{p*}$, $\pi_t^{w*}$ and $\omega_t^*$ are

$$\lambda_x x_t + \kappa_y^p \eta_t^1 + \kappa_y^w \eta_t^2 = 0, \tag{I.7}$$

$$\lambda_p \pi_t^p - \eta_t^1 + \gamma \eta_t^4 + \eta_t^3 = 0, \tag{I.8}$$

$$\lambda_w \pi_t^w - \eta_t^2 + \gamma \eta_t^5 - \eta_t^3 = 0, \tag{I.9}$$

$$\kappa_c^p \eta_t^1 - \kappa_c^w \eta_t^2 + \eta_t^3 - \beta \mathbb{E}_t \eta_{t+1}^3 + \gamma \eta_t^6 = 0, \tag{I.10}$$

$$\frac{\beta^2(1-\mu^p)}{1-\beta\mu^p} \mathbb{E}_t \eta_{t+1}^1 - \eta_t^4 + \beta(1-\gamma) \mathbb{E}_t \eta_{t+1}^4 = 0, \tag{I.11}$$

$$\frac{\beta^2(1-\mu^w)}{1-\beta\mu^w} \mathbb{E}_t \eta_{t+1}^2 - \eta_t^5 + \beta(1-\gamma) \mathbb{E}_t \eta_{t+1}^5 = 0, \tag{I.12}$$

$$\beta^2(1-\mu^p)\zeta^p \mathbb{E}_t \eta_{t+1}^1 - \beta^2(1-\mu^w)\zeta^w \mathbb{E}_t \eta_{t+1}^2 - \eta_t^6 + \beta(1-\gamma) \mathbb{E}_t \eta_{t+1}^6 = 0. \tag{I.13}$$

The optimal policy that abstracts from the costs of wage dispersion is characterized in the same way, except that $\lambda_w = 0$ in equation (I.9).

# J Real Wage Rigidity under Different Calibrations of Wage Changes

Figures J.1 and J.2 replicate Figure 8, but under different calibrations of the wage-change parameter $\mu^w$: more rigid real wages with a higher probability of not changing real wages

($\mu^w = 0.9$) and more flexible real wages with a lower probability of not changing real wages ($\mu^w = 0.5$).

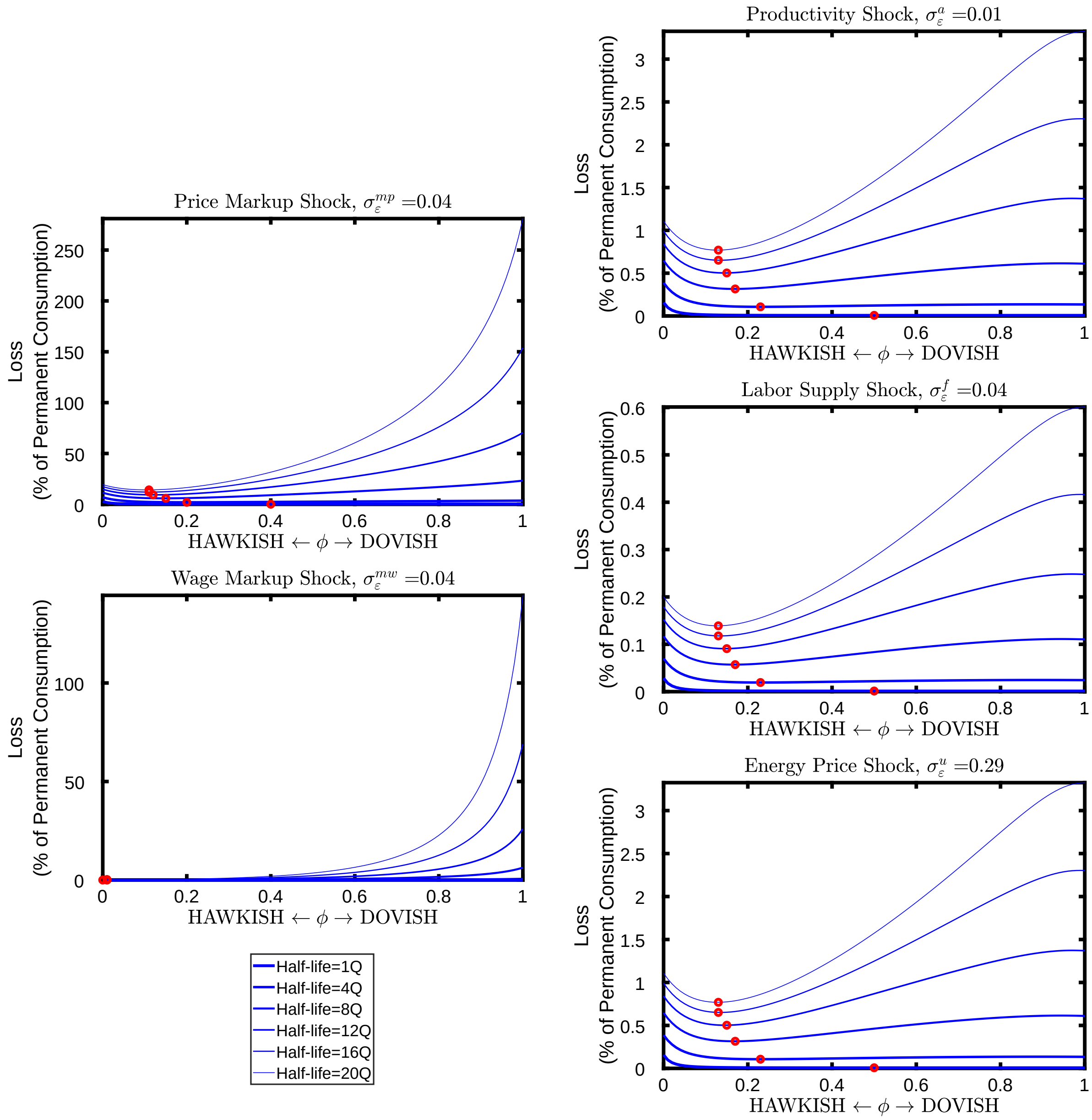


Figure J.1: Loss Function under Real Wage Rigidity and Rational Expectations, $\mu^w = 0.9$

*Note: For each type of supply shock, the figure plots the loss function of the central bank (51) as a function of the weight $\phi$ on the output gap in the objective (26) of the central bank, under the assumption that the economy is hit by this one type of shock only. It does so for different levels of persistence of the shock, captured by the half-life of the AR(1) process. On each curve, the red dot corresponds to the minimum of the curve, that is the optimal policy within the class of policies (26). The calibration is given in the "Default Calibration" column of Table 1.*

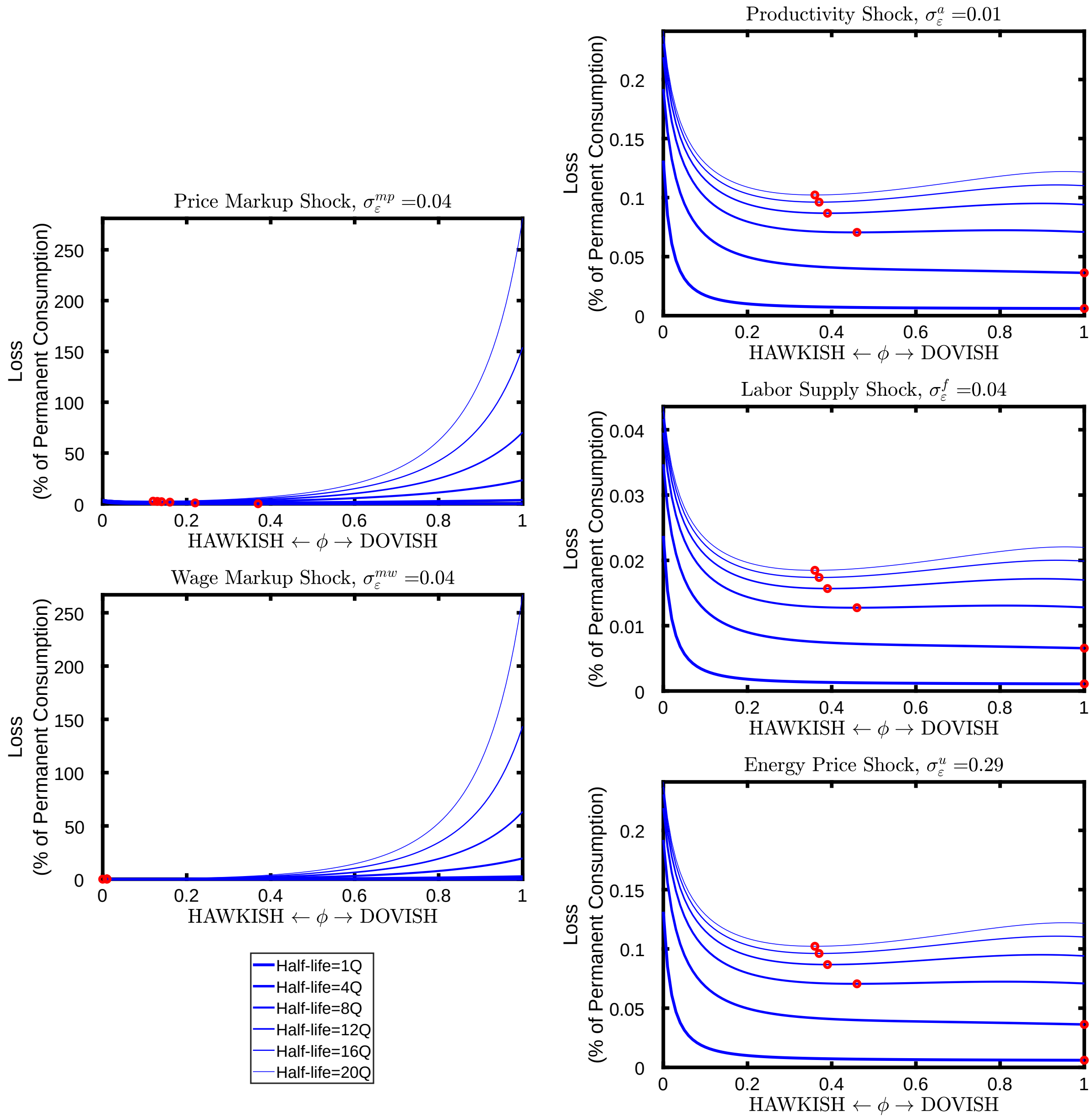


Figure J.2: Loss Function under Real Wage Rigidity and Rational Expectations, $\mu^w = 0.5$

*Note: For each type of supply shock, the figure plots the loss function of the central bank (51) as a function of the weight $\phi$ on the output gap in the objective (26) of the central bank, under the assumption that the economy is hit by this one type of shock only. It does so for different levels of persistence of the shock, captured by the half-life of the AR(1) process. On each curve, the red dot corresponds to the minimum of the curve, that is the optimal policy within the class of policies (26). The calibration is given in the "Default Calibration" column of Table 1.*

# K Optimal Policy Under Rational Expectations and Real Wage Rigidity

The central bank seeks to minimize (51) subject to (27), (50) and (32). Let $\eta_t^1, \eta_t^2, \eta_t^3$ be the Lagrange multipliers on the three constraints. The first-order conditions of the central bank's program with respect to $\pi^p$, $x$, $\Delta$ and $\omega$ are

$$\lambda_p \pi_t^p - \eta_t^1 + \eta_{t-1}^1 = 0, \tag{K.1}$$

$$\lambda_x x_t + \kappa_y^p \eta_t^1 + \kappa_y^w \eta_t^2 = 0, \tag{K.2}$$

$$\lambda_w \Delta_t - \eta_t^2 + \eta_{t-1}^2 - \eta_t^3 = 0, \tag{K.3}$$

$$\kappa_c^p \eta_t^1 - \kappa_c^w \eta_t^2 + \eta_t^3 - \beta \mathbb{E}_t \eta_{t+1}^3 = 0. \tag{K.4}$$

# L Derivation of the Wage Phillips Curves under Real Wage Rigidity and Adaptive Expectations

The wage-setting equation (48) can be written

$$\omega_t^* - \omega_t = (1-\beta\mu^w)\sum_{k=0}^{\infty}(\beta\mu^w)^k \tilde{\mathbb{E}}_t\Bigg(\zeta^w\Bigg(mrs_{t+k} + m_{t+k}^w - \omega_t\Bigg) + (1-\zeta^w)\Bigg(\omega_{t+k} - \omega_t\Bigg)\Bigg) \tag{L.1}$$

Expectations of real wage growth can be written

$$\tilde{E}_t(\omega_{t+k} - \omega_t) = \tilde{E}_t\left(\sum_{i=1}^{k} \pi_{t+i}^w - \pi_{t+i}^p\right), \tag{L.2}$$

Using this, and isolating the time-$t$ term, equation (L.1) can be written

$$\begin{aligned}\omega_t^* - \omega_t = (1-\beta\mu^w)\zeta^w\Bigg(mrs_t + m_t^w - \omega_t\Bigg) + (1-\beta\mu^w)\zeta^w\sum_{k=1}^{\infty}(\beta\mu^w)^k\tilde{\mathbb{E}}_t\Bigg(mrs_{t+k} + m_{t+k}^w - \omega_t\Bigg) \\ + (1-\zeta^w)\sum_{k=1}^{\infty}(\beta\mu^w)^k\tilde{\mathbb{E}}_t\Bigg(\pi_{t+k}^w - \pi_{t+k}^p\Bigg)\end{aligned} \tag{L.3}$$

Using (49) and the fact that expectations at all horizons are the same, it can be rewritten as

$$\begin{aligned}\omega_t - \omega_{t-1} = {} & \kappa_c^w(\omega_t^e - \omega_t + m_t^w) + \kappa_y^w x_t + \beta(1-\mu^w)\zeta^w(mrs_{t-1}^* - \omega_t + m_{t-1}^{w*}) \\ & + \frac{\beta(1-\mu^w)}{1-\beta\mu^w}(1-\zeta^w)(\pi_{t-1}^{w*} - \pi_{t-1}^{p*}).\end{aligned} \tag{L.4}$$

Using the assumption that unions expect future $c$, $n$ (hence the mrs) and future shocks to be at their steady-state values, it gives equation (54) in the text.

# M Derivation of the Wage Phillips Curves under Real Wage Rigidity and Adaptive Expectations Variant

Start again from equation (L.1). Isolating the time-$t$ term, it can be rewritten

$$\begin{aligned}\omega_t^* - \omega_t = (1-\beta\mu^w)\zeta^w\Big(mrs_t + m_t^w - \omega_t\Big) & + (1-\beta\mu^w)\zeta^w \sum_{k=1}^{\infty}(\beta\mu^w)^k\tilde{\mathbb{E}}_t\Big(mrs_{t+k} + m_{t+k}^w - \omega_t\Big) \\ & + (1-\beta\mu^w)(1-\zeta^w)\sum_{k=1}^{\infty}(\beta\mu^w)^k\tilde{\mathbb{E}}_t\Big(\omega_{t+k} - \omega_t\Big).\end{aligned} \tag{M.1}$$

Using (49) and the fact that expectations at all horizons are the same, it can be rewritten as

$$\begin{aligned}\omega_t - \omega_{t-1} = {} & \kappa_c^w(\omega_t^e - \omega_t + m_t^w) + \kappa_y^w x_t + \beta(1-\mu^w)\zeta^w(mrs_{t-1}^* - \omega_t + m_{t-1}^{w*}) \\ & + \beta(1-\mu^w)(1-\zeta^w)(\omega_{t-1}^* - \omega_t).\end{aligned} \tag{M.2}$$

Using the assumption that unions expect future $c$, $n$ (hence the mrs) and future shocks to be at their steady-state values, it gives

$$\omega_t - \omega_{t-1} = \kappa_c^w(\omega_t^e - \omega_t + m_t^w) + \kappa_y^w x_t - \beta(1-\mu^w)\zeta^w\omega_{t-1}^* + \beta(1-\mu^w)(\omega_{t-1}^* - \omega_t). \tag{M.3}$$

Together with the price Phillips curve under the adaptive expectations variant (I.5), it characterizes the economy under real wage rigidity and the adaptive expectations variant.

Figure M.1 represents the ranking of the different policies (26) as in Figure 1 but under the joint assumptions of real wage rigidity and the adaptive expectations variant. Results are very similar to the case of real wage rigidity and the main specification of adaptive expectations in Figure 9.

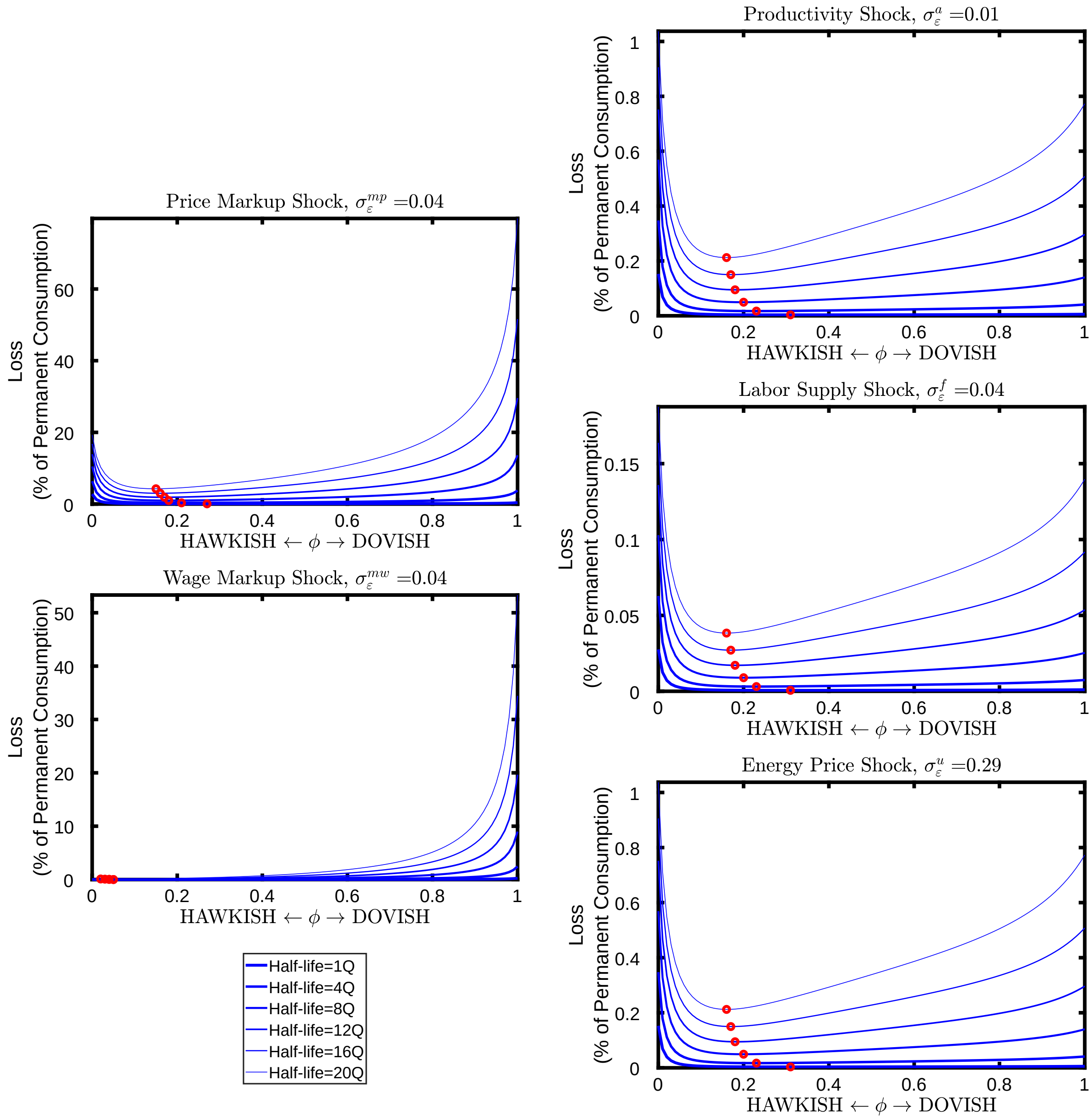


Figure M.1: Loss Function under Real Wage Rigidity and Adaptive Expectations Variant

*Note: For each type of supply shock, the figure plots the loss function of the central bank (51) as a function of the weight $\phi$ on the output gap in the objective (26) of the central bank, under the assumption that the economy is hit by this one type of shock only. It does so for different levels of persistence of the shock, captured by the half-life of the AR(1) process. On each curve, the red dot corresponds to the minimum of the curve, that is the optimal policy within the class of policies (26). The calibration is given in the "Default Calibration" column of Table 1.*

# N Optimal Policy Under Adaptive Expectations and Real Wage Rigidity

The central bank seeks to minimize (51) subject to (41), (54), (32), (39) and (40). Let $\eta_t^1, \eta_t^2, \eta_t^3, \eta_t^4, \eta_t^5$ be the Lagrange multipliers on the five constraints. The first-order conditions of the central bank's program with respect to $x_t$, $\pi_t^p$, $\Delta_t$; $\omega_t$, $\pi_t^{p*}$ and $\pi_t^{w*}$ are

$$\lambda_x x_t + \kappa_y^p \eta_t^1 + \kappa_y^w \eta_t^2 = 0, \quad \text{(N.1)}$$

$$\lambda_p \pi_t^p - \eta_t^1 + \gamma\eta_t^4 + \gamma\eta_t^5 = 0, \quad \text{(N.2)}$$

$$\lambda_w \Delta_t - \eta_t^2 + \gamma\eta_t^5 - \eta_t^3 = 0, \quad \text{(N.3)}$$

$$(\kappa_c^p + \beta(1-\mu^p)\zeta^p)\eta_t^1 - (\kappa_c^w + \beta(1-\mu^w)\zeta^w)\eta_t^2 + \eta_t^3 - \beta\mathbb{E}_t\eta_{t+1}^3 = 0, \quad \text{(N.4)}$$

$$\frac{\beta^2(1-\mu^p)}{1-\beta\mu^p}(1-\zeta^p)\mathbb{E}_t\eta_{t+1}^1 - \frac{\beta^2(1-\mu^w)}{1-\beta\mu^w}(1-\zeta^w)\mathbb{E}_t\eta_{t+1}^2 - \eta_t^4 + \beta(1-\gamma)\mathbb{E}_t\eta_{t+1}^4 = 0, \quad \text{(N.5)}$$

$$\frac{\beta^2(1-\mu^p)}{1-\beta\mu^p}\zeta^p\mathbb{E}_t\eta_{t+1}^1 + \frac{\beta^2(1-\mu^w)}{1-\beta\mu^w}(1-\zeta^w)\mathbb{E}_t\eta_{t+1}^2 - \eta_t^5 + \beta(1-\gamma)\mathbb{E}_t\eta_{t+1}^5 = 0. \quad \text{(N.6)}$$

# O Optimal Policy Under Adaptive Expectations Variant and Real Wage Rigidity

The central bank seeks to minimize (51) subject to (I.5), (M.3), (32), (39) and (45). Let $\eta_t^1, \eta_t^2, \eta_t^3, \eta_t^4, \eta_t^6$ be the Lagrange multipliers on the five constraints. The first-order conditions of the central bank's program with respect to $x_t$, $\pi_t^p$, $\Delta_t$; $\omega_t$, $\pi_t^{p*}$ and $\omega_t^*$ are

$$\lambda_x x_t + \kappa_y^p \eta_t^1 + \kappa_y^w \eta_t^2 = 0, \quad \text{(O.1)}$$

$$\lambda_p \pi_t^p - \eta_t^1 + \gamma\eta_t^4 = 0, \quad \text{(O.2)}$$

$$\lambda_w \Delta_t - \eta_t^2 - \eta_t^3 = 0, \quad \text{(O.3)}$$

$$\kappa_c^p \eta_t^1 - (\kappa_c^w + \beta(1-\mu^w))\eta_t^2 + \eta_t^3 - \beta\mathbb{E}_t\eta_{t+1}^3 + \gamma\eta_t^6 = 0, \quad \text{(O.4)}$$

$$\frac{\beta^2(1-\mu^p)}{1-\beta\mu^p}\mathbb{E}_t\eta_{t+1}^1 - \eta_t^4 + \beta(1-\gamma)\mathbb{E}_t\eta_{t+1}^4 = 0, \quad \text{(O.5)}$$

$$(\beta^2(1-\mu^p)\zeta^p)\mathbb{E}_t\eta_{t+1}^1 + (\beta^2(1-\mu^w)(1-\zeta^w))\mathbb{E}_t\eta_{t+1}^2 - \eta_t^6 + \beta(1-\gamma)\mathbb{E}_t\eta_{t+1}^6 = 0. \quad \text{(O.6)}$$