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10194
2022

December 2022

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CESifo

Impressum:

CESifo Working Papers
ISSN 2364-1428 (electronic version)
Publisher and distributor: Munich Society for the Promotion of Economic Research - CESifo GmbH
The international platform of Ludwigs-Maximilians University's Center for Economic Studies and the ifo Institute
Poschingerstr. 5, 81679 Munich, Germany
Telephone +49 (0)89 2180-2740, Telefax +49 (0)89 2180-17845, email office@cesifo.de
Editor: Clemens Fuest
https://www.cesifo.org/en/wp
An electronic version of the paper may be downloaded
· from the SSRN website: www.SSRN.com
· from the RePEc website: www.RePEc.org
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CESifo *Working Paper No. 10194*

Inflation Surprises in a New Keynesian Economy with a True Consumption Function

Abstract

The resurgence of inflation since the late 2021 is now accompanied by a reversal of prospects of growth, reviving fears of stagflation across the world (IMF 2022, World Bank 2022). In almost all accounts of the mounting stagflation threats a prominent role is played by the fall of households' purchasing power, and hence consumption, owing to the inflation shock *visà-vis* nominal wages lagging behind. The theoretical issue that motivates this paper is that this endogenous real income effect of inflation surprises, independent of restrictive monetary policy, is not present in the standard New Keynesian models for monetary policy. The paper shows how this channel can be introduced reformulating the consumption function, with the consequence that it exerts a stabilisation effect on inflation endogenously. By means of simulations the paper discusses the main monetary policy implication: what is the role left to monetary policy which purports to curb inflation in the same way?

JEL-Codes: E170, E300, E500.

Keywords: cost-push inflation, real income effect, stagflation, New Keynesian models for monetary policy.

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December 2022

1. Introduction

Since late 2021, with the rebound of the world economy after the COVID-19 pandemic, almost everywhere consumer prices have been rising much faster than anticipated by professional forecasters and official institutions on a long, medium and even short term horizon. Table 1 reports the point value of inflation forecasts in the Survey of Professional Forecasters of the European Central Bank (ECB), showing that inflation acceleration beyond the 2% target jump started in the fourth quarter of 2021 to a largely unanticipated extent even on a short-term horizon. We may well speak, in macroeconomic jargon, of an "inflation surprise".

Table 1. Quarterly observations of annual inflation in the euro area and earlier forecasts (percent rate of change of HICP)

Quarters	Observed	Current calendar year SPF[a]	1-year earlier SPF	2-years earlier SPF
2021:1	1.0	0.9	1.3	1.7
2021:2	1.8	1.6	1.0	1.6
2021:3	2.9	1.9	1.1	1.5
2021:4	4.7	2.3	1.1	1.4
2022:1	6.1	3.0	1.3	1.4
2022:2	8.0	6.0	1.3	1.4
2022:3	9.3	7.3	1.4	1.3

[a]End-of-year forecast in the given quarter

Source: ECB Statistical Warehouse

The resurgence of inflation is now accompanied by a reversal of prospects of growth, reviving fears of stagflation, the combination of high inflation and stagnating economic activity that plagued the advanced economies in the 1970s (IMF 2022, World Bank 2022). As an example, the October 2022 *World Economic Outlook* by the International Monetary Fund foresaw a generalised slowdown of economic activity in 2022-2023, worse than in the previous *Outlook* of April 2022 (see Table 2[1]

[1] "More than a third of the global economy will contract this year or next, while the three largest economies—the United States, the European Union, and China—will continue to stall. In short, the worst is yet to come, and for many people 2023 will feel like a recession" (IMF 2022, p. xiii).

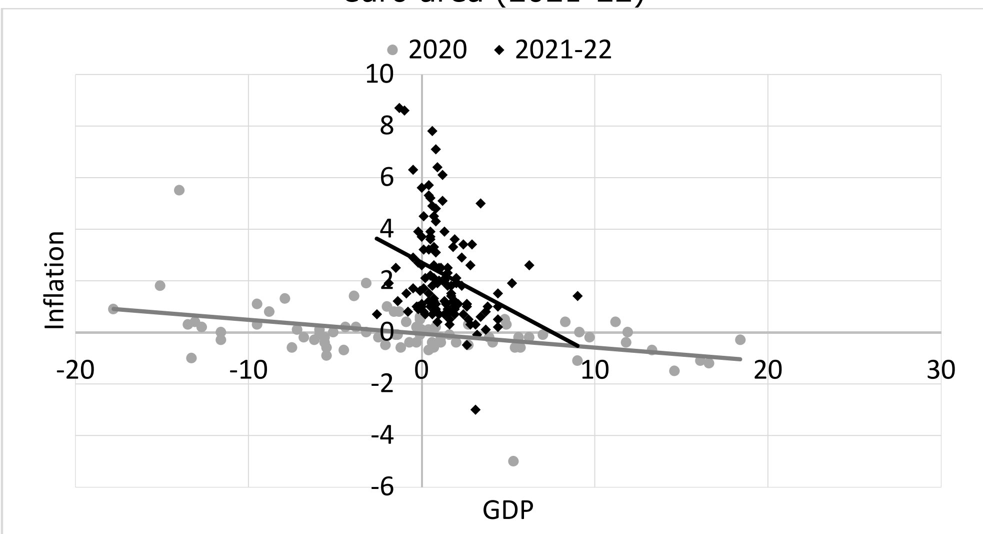
Table 2. Overview of the *World Economic Outlook* projections (percent changes)

	Projections			Difference from April 2022	
	2021	2022	2023	2022	2023
World	6.1	3.2	2.7	–0.4	–0.9
Advanced economies	5.2	2.4	1.1	–0.9	–1.3
United States	5.7	1.6	1.0	–2.1	–1.3
Euro area	5.4	3.1	0.5	–0.2	–1.8
Japan	1.7	1.7	1.6	–0.7	–0.7
United Kingdom	7.4	3.6	0.3	–0.1	–0.9
Canada	4.5	3.3	1.5	–0.5	–1.3
Others	5.1	2.8	2.3	–0.3	–0.7

Source: IMF (2022)

As far as the euro area (EA) is concerned, the comparison of the output-inflation relationship during the pandemic (2020) and in the subsequent two years in Figure 1 is remarkable. In 2020 the relationship appeared quite flat, which means that the large swings in GDP growth induced by the pandemic[2] had almost no counterpart in changes in the Harmonized Index of Consumer Prices (HICP) which remained within a narrow corridor around zero. Since 2021-22 the relationship has changed dramatically. GDP growth has been shrinking with HICP inflation escalating three-four times above the official target of 2%.

Figure 1. Annual percent changes of GDP and inflation on a quarterly basis in the euro area (2021-22)



Source: Elaborations on EUROSTAT, Quarterly statistics

[2] The negative values of GDP growth mostly refer to the first, second and fourth quarter of 2020, the positive values to the third quarter.

Incipient stagflation is widely traced back to the basic macroeconomic notion that it is the result of economy-wide supply-side shocks. These can be of two types largely present in the post-pandemic global scenario. *Cost-push shocks*, typically due to skyrocketing prices of raw materials and energy inputs (to which catching-up wages may add), such that firms *can produce as much as before*, at the same level of margins, provided they can transfer higher costs to sale prices. *Shocks to production capacity*, such that firms *cannot produce as much as before* owing to restraints such as shortages of input supplies, disruption of production chains, breakdown of technological systems, other external constraints (lockdowns are a recent major example); the resulting imbalance between supply and demand exerts pressure on prices. The differences between the two types of shocks are important, but to the extent that *aggregate demand falls as prices rise*, the result in either case is that markets clear with lower output and higher prices.

It is arguable that, whereas the EA presents clearer symptoms of inflation driven by prevalent supply-side factors (ECB 2022a, 2002b, n. 3, Battistini et al. 2022), among the advanced economies inflation in the United Kingdom and the United States seem also fuelled by demand-side factors, possibly owing to overstimulation in the later phase of the pandemic – as famously warned by Lawrence Summers after the Biden Administration's fiscal package[3] (Bailey 2022, Powell 2022). Yet it is also a basic macroeconomic notion that demand-side inflation is characterised by (temporary) acceleration, not slowdown, of economic activity. A more accurate interpretation may be that demand-side pressure *vis-à-vis* worsening supply-side conditions has spurred inflation initially, while aggregate demand and output are now expected to retrench in order to rebalance with supply.

As a matter of fact, all major central banks are now quickly lifting their policy rates from the zero lower bound were they have been stuck for a decade. However, they still remain in *negative territory* in real terms (IMF 2022, p. 6). In the October 2022 issue of the ECB *Economic Bulletin* the data show that the yield curve at all maturities is systematically below the correspondent inflation forecast, with convergence taking place towards 2% at the very far end (10+ years), which actually means zero real interest rate (ECB 2022b, n. 6, pp. 29-30).

In addition, long-lived scepticism, revived by the limited success of the unprecedented monetary stimuli over the past ten years, surrounds the responsiveness of aggregate demand components to the relevant real interest rates (Schnabel 2020 and the literature cited therein). This is to say that monetary tightening, in terms of timing and intensity as well, cannot yet be regarded as the

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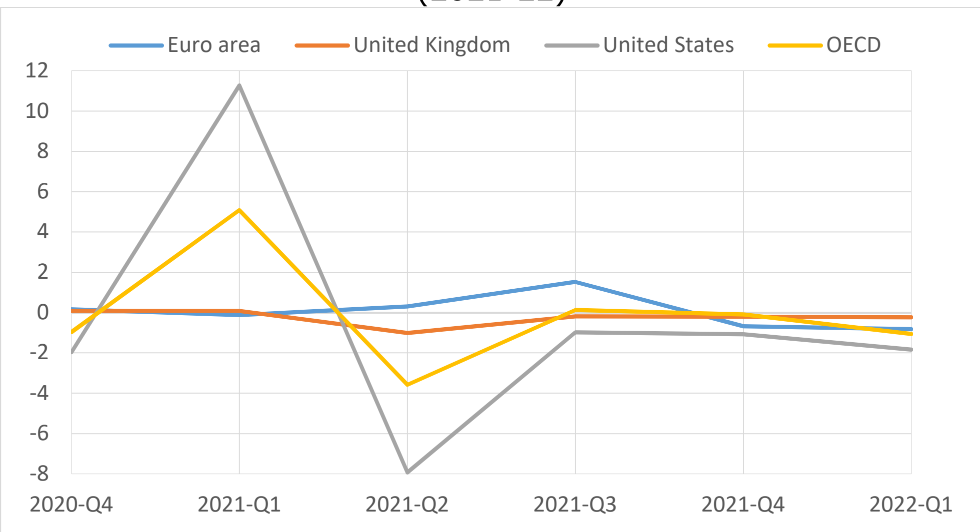
[3] (*The Washington Post*, February 4, 2021)

main, let alone exclusive, driving force of the downturn of growth prospects across the advanced economies.

In almost all accounts of the mounting stagflation threats a prominent role is played by the fall of households' purchasing power, and hence consumption, owing to the inflation shock *vis-à-vis* slow upgrading of nominal wages (Battistini et al. 2022, World Bank 2022, IMF 2022, ECB 2022a).[4] The same concern, especially where the incidence of imported energy inflation is stronger, spurs governments to implement fiscal measures apt to shield households' (and firms') budgets against unsustainable energy bills.[5] Figure 2 provides evidence of the braking of the post-pandemic recovery of households' real disposable income across advanced economies in parallel with the acceleration of inflation since the end of 2021, turning into negative growth in 2022.

Figure 2. Quarterly percent rate of change of households' real disposable income (2021-22)



Source: OECD, Quarterly National Accounts

The theoretical issue that motivates this paper is that the endogenous real income channel of stagflation found in the data is not present in the now standard formulations of New Keynesian (NK) models for monetary policy, from the foundational ones (e.g. Clarida et al. 1999, 2000, Woodford 2003) to the subsequent

[4] Once again, nominal wage dynamics appears stronger in US and UK than in the euro area, but it does not seem sufficient to shield households' purchasing power at large (Krugman 2022, IMF 2022, and here Figure 2). "The global economy continues to face steep challenges, shaped by the lingering effects of three powerful forces: the Russian invasion of Ukraine, a cost-of-living crisis caused by persistent and broadening inflation pressures, and the slowdown in China" (IMF 2022, p. xiii).

[5] In September 2022 Germany launched a 200 billion euros plan of government cheques to pay for energy bills of households and firms.

specialised advances (Galì 2008, Christiano et al. 2010, Smets et al. 2010, Schmidt and Wieland 2013). Though "nominal rigidities" are the hallmark of NK macroeconomics, these models contain no negative transmission channel between inflation shocks and GDP *except a monetary restriction* aimed at curbing inflation by first raising the policy interest rate more than inflation in compliance with the so-called "Taylor Principle". Since the inflation shock *per se* does not impinge upon aggregate demand and GDP, which may even *rise* if excess inflation is translated into lower real interest rates, monetary tightening is the single tool that grants the system's stabilisation.[6]

In order to fill this gap, this paper in section 2 first reviews the foundations of the NK IS function based on the optimal consumption path (the Euler equation) of households, arguing that this is not a proper consumption function in the usual meaning, i.e. the determination of the *level* of consumption at a given point in time in relation to a set of variables, among which, in light of standard micro-foundations, one expects to see present and future real income streams.[7] In other words, the NK IS reproduces the substitution effect on consumption of changes in real interest rate, but it misses the real income effects due to shifts of households' intertemporal budget for a given real interest rate. The reason for this oddity is that in the standard NK model households' intertemporal budget constraint is not explicited.

Section 3 therefore shows how to obtain the NK IS with a "true" consumption function derived from households' optimal intertemporal consumption plan under their budget constraint. The key result is that, as long as nominal incomes are not perfectly indexed to the consumer price index – a condition for which the NKs have provided theory and evidence (e.g. Taylor 1980, Galì 2013) – the IS displays *both* the usual substitution effect in relation to the real interest rate *and* an income effect due to unanticipated shocks to current real income, a cause of which may be an "inflation surprise". In essence, a result in line with Friedman's (1957) and Hall's (1988) Permanent Income Hypothesis. This income effect provides the NK economy with the missing ring between inflation shocks a fall in aggregate demand and in GDP *independently* of monetary policy, the ring which is now at the centre of attention as a cause of the gloomy economic prospects.

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[6] This point marks a major difference between NK macroeconomics and older traditions whereby the negative relationship between aggregate demand and the price level (if not the inflation rate directly) was due to the real balance effect, i.e. the fall of purchasing power of money holdings, notably independent of any monetary policy intervention (e.g. Dornbusch and Fischer 1981).

[7] The same point was raised by Smith and Wickens (2006).

This amended version of the NK IS has also important implications for monetary policy. If an inflation surprise can reduce aggregate demand and restrain output by itself, what is the role left to monetary policy which purports to curb inflation in the same way? To address this issue, section 4 presents simulations of an empirical NK three-equation model where the new IS is combined with the standard Phillips Curve (PC) and the Taylor Rule (TR). By empirical model it is meant that the microfoundations of the Phillips Curve and the Taylor Rule are not fully explicited while the relevant parameters are set according to the prevailing findings in the literature. Simulations only consist of an inflation (energy cost-push) shock to the PC, a treatment consistent with the fact that the PC under sticky prices is derived from firms' reactions to changes in marginal costs (as in the benchmark model by Calvo 1983). For the sake of clarity, the other type of supply-side shocks that may lead to stagflation, those to firms' production capacity, are not considered in this work and left for further investigation.

Simulations reproduce different scenarios dependent on different dynamic specifications of the two key variables leading the inflation process, the cost shocks and inflation expectations. As baseline case, the "easiest" scenario is considered, namely one where the shock is transitory – as it was deemed to be worldwide at the beginning – and expectations remain anchored to the central bank's official target – as was also found initially, and partly still is. Two are the main findings. First, it is confirmed that the inflation shock can be reabsorbed through the income effect restraining demand and output even with monetary policy standing neutral. Second, the only contribution added by monetary tightening dictated by the TR is to keep the inflation deviation from target smaller at the expense of larger negative output gaps.

However, at the core of concerns of all major central bankers, and as a compelling motivation to shift to the restrictive stance, one finds alleged risks of jumping on a dynamically unstable path of inflation (Bailey 2022, Powell 2022, ECB 2022a). Such risks are traced back to the interplay between persistency of energy shocks, de-anchored expectations and indexed incomes. These elements are introduced in turn. First, an inflation shock that mimics an epidemic curve with an initial self-sustained increase – as we have been witnessing since 2021. Then, expectations are allowed to de-anchor partially, with a fraction of agents tracking closely the path of the shock and feeding the inflation process. Finally, a fraction of households have their nominal incomes indexed to observed inflation.

The interesting result of the simulations is that each of these harder conditions indeed amplify the inflation process (wider inflation and output gaps) but still the system converges to the zero gaps equilibrium even with neutral monetary policy.

It is only the interaction of all three factors, under particularly high fractions of de-anchored expectations and indexed incomes that may *generate dynamic instability endogenously*. Under *these* conditions, Taylor-ruled monetary policy becomes essential to guarantee the dynamic stability of the inflation process.

Finally section 5 summarises and concludes emphasising that the results presented in this paper do not mean that the current motivations of central banks for taking resolute actions to curb inflation are groundless. History teaches that inflation process can indeed get out of control. What the paper shows is that, and how, threats of *endogenous dynamic instability* should be purposefully grafted onto today's mainstream model for policymaking, which may hopefully provide better guide in the face of current challenges.

2. The basic New Keynesian IS

Let us first examine the basic NK model. The IS equation is derived from the representative households' "consumption function" (I use inverted commas for the reason that will be explained shortly), under the condition that, absent investment, the output market clears at any date, $C_t = Y_t$.

The representative household is assumed to maximise the following intertemporal utility function

(1) $$\sum_{n=0}^{\infty} \Theta^{-n} U(C_{t+n})$$

where $U(C_t)$ is the period utility with all the standard properties, $\Theta \equiv (1 + \theta)$, and $\theta > 0$ is the rate of time preference. For the time being, it is assumed that future variables are known with certainty.

At each date t, the household receives a flow of incomes and should decide how much to consume, to save or to borrow. In order to save or borrow, the household has free and unlimited access to the capital market at the current interest rate. All saving and borrowing operations have one-period duration, with interest payments falling due ex post. Previous saving or borrowing decisions determine the household's net worth at end of t–1, and the ensuing interest payments in t.

To deal with the problem at hand, it is better to begin with writing the household's consumable resources in each t in monetary values (denoted by the superscript ($^{\mathrm{m}}$))

(2) $$C^{\mathrm{m}}_t = X^{\mathrm{m}}_t + A^{\mathrm{m}}_{t-1} i_{t-1} - S^{\mathrm{m}}_t$$

where X^{m} = non-capital income, A^{m} = net worth, $S^{\mathrm{m}} = A^{\mathrm{m}}_t - A^{\mathrm{m}}_{t-1}$ (i.e. $S^{\mathrm{m}} > 0$ denotes saving, $S^{\mathrm{m}} < 0$ denotes borrowing), i = nominal interest rate. The latter is supposed to be under control of the central bank, and hence we will call it the policy rate.

The consumption budget constraint can also be rewritten as:

(3) $C^{m}_{t} = X^{m}_{t} + A^{m}_{t-1}(1 + i_{t-1}) - A^{m}_{t}$

Since utility depends on real consumption, let P_t be the current consumer price index (CPI), and π_t the current CPI inflation rate, so that $P_t = (1 + \pi_t)P_{t\text{-}1}$. Consequently, dividing all nominal values by P_t, the real consumption budget constraint results to be:

(4) $C_t = X_t + A_{t-1}(1 + r_t) - A_t$

where $(1 + r_t) = (1 + i_{t-1})/(1 + \pi_t)$ is the gross real interest rate. Note that the nominal part is known and set at the moment of the saving or borrowing operation, whereas the real value depends on the realised inflation ex post.

The NK "consumption function" is, more precisely, the optimal consumption path (or Euler equation) that results from maximisation of the programme (1) under the sequence of consumption budget constraints (3) from t onwards. The general (first-order) solution requires that, at each time step $(t, t+1)$ the intertemporal marginal rate of substitution of consumption dictated by subjective utility equates the rate of substitution dictated by the capital market, i.e. the market real interest rate to be earned on saving (to be paid on borrowing) in one time unit, r_{t+1}.

Let $R_{t+1} \equiv (1 + r_{t+1})$ be the gross real rate, given by $(1 + i_t)/(1 + \pi_{t+1})$. Consequently, the Euler equation is

(5) $U'(C_t)/\ U''(C_t) = R_{t+1}/\Theta$

For most common utility functions, the Euler equation takes the form

(6) $C_{t+1}/C_t \equiv G_c = f(R_{t+1}, \Theta)$ $\qquad f_r > 0, f_\theta < 0$

That is to say, the solution yields the *optimal consumption growth path* as a function increasing in the market real rate and decreasing in the rate of time preference. Hence, an increase in r_{t+1} incentivises households to tilt the consumption path towards the future (i.e. a higher growth path), whereas an increase in θ works in the opposite direction. It is also common to find that $G_c = 1$ for $r_{t+1} = \theta$, that is a constant consumption path.

Let us consider as an example this widely used specification

(7) $$U(C_t) = \frac{C_t^{1-\sigma} - 1}{1-\sigma}$$

such that $U(C_t) \geq 0$ for $C_t \geq 1$, $\sigma > 0$, and $1/\sigma \equiv \eta$ is the constant elasticity of intertemporal substitution (CES), which yields

(8) $G_c = (R_{t+1}/\Theta)^{\eta}$

The NK "consumption function" is precisely equation (8) re-expressed as follows:

(9) $C_t = C_{t+1}(R_{t+1}/\Theta)^{-\eta}$

The IS equation is then obtained imposing the output market clearing condition, $C_t = Y_t$ at all dates, so that

(10) $Y_t = Y_{t+1}(R_{t+1}/\Theta)^{-\eta}$

Recalling that $R_{t+1} = (1 + i_t)/(1 + \pi_{t+1})$, this takes the form of the traditional inverse relationship between Y_t and i_t, with elasticity $-\eta$, .

3. The New Keynesian IS with a true consumption function

Strictly speaking, the Euler equation is not a consumption function as is commonly understood, i.e. the *level* of consumption at each date in relation to a set of variables.[8] To put it in simple words, the NK formulation of consumption only deals with the substitution effect of changes in the real interest rate, but it is mute about the income effect as real income changes. Moreover, the NK key deduction from the Euler equation that a change in the (expected) real interest rate affects current consumption with opposite sign is unwarranted. The Euler equation only says that G_c should rise (fall), which may well be due to a rise (fall) of C_{t+1} with little or no effect on C_t.

This misuse of the Euler equation is revealed by the popular idea that the NK consumption function is forward looking. This usually means that current consumption "depends on" future consumption as if the latter were an independent variable on the right-hand side of the equation. This interpretation is not correct because the only information the Euler equation (6) conveys is the optimal *growth path* of consumption over time, i.e. the optimal G_c given the r-h-s variables. Once G_c is established, one can say that C_t "depends on" C_{t+1} as much as the other way round.

To obtain a complete account of how current consumption is affected by the business cycle or monetary policy a "true" consumption function is needed, and to this end the budget constraint should be employed.

The general representation of the sequence of the consumption budget constraint (3) from date t and $n = 1, \ldots, T$ dates ahead is in present value (PV) terms as follows:

[8] This argument is also developed by Smith and Wickens (2006).

$$\underbrace{C_t^{\mathrm{m}} + \sum_n \frac{C^{\mathrm{m}}{}_{t+n}}{\prod_n (1+i_{t+n-1})}}_{\text{PV of consumption}} = \underbrace{\left(X_t^{\mathrm{m}} + \sum_n \frac{X_{t+n}^{\mathrm{m}}}{\prod_n (1+i_{t+n-1})} \right)}_{\text{PV of non-capital incomes}} +$$

(11)

$$+ \underbrace{A^{\mathrm{m}}{}_{t-1} i_{t-1} \left(1 + \sum_n \frac{1}{\prod_n (1+i_{t+n-1})} \right)}_{\substack{\text{PV of interest payments} \\ \text{(on initial net worth)}}} - \underbrace{\frac{A_T^{\mathrm{m}} - A_{t-1}^{\mathrm{m}}}{(1+i_{t-1})^T}}_{\substack{\text{PV of net worth} \\ \text{final change}}} \text{ , and } A_T^{\mathrm{m}} \geq 0$$

Note the well-known principle of intertemporal budgeting according to which intermediate saving and borrowing decisions *do not affect* the PV of total consumable resources, which only depends on the PV of non-capital incomes, the PV of interest payments on *initial* net worth, and on the PV of the (planned) change of net worth at the end of plan. For our present purposes, it is convenient to assume $A^{\mathrm{m}}{}_T = A^{\mathrm{m}}{}_{t\text{-}1} = 0$.[9] Consequently, the PV of consumption is constrained by just the PV of non-capital incomes (incomes for short).

To translate the PV of consumption in current real terms let us divide both sides of (11) by P_t. Knowing that

$$P_{t+n} = P_t \prod_n (1 + \pi_{t+n})$$

we can write

(12) $$C_t + \sum_n C_{t+n} R(n)^{-1} = X_t^{\mathrm{m}} / P_t + \sum_n (X_{t+n}^{\mathrm{m}} / P_{t+n}) R(n)^{-1}$$

where $R(n)$ is the compound real interest rate up to n ($R(1) = 1+r_{t+1}$, $R(2) = (1+r_{t+1})(1+r_{t+2})$, ...).

The determination of this consumption budget constraint entails a remarkable information load for the household, namely the entire sequence of future nominal incomes, policy interest rates, and inflation rates. Moreover, it is natural to consider the case, and it is usually done, that the future variables are uncertain. The information load is however lightened by restricting the household's task to the case where the future variables move randomly around their steady-state (SS) equilibrium (denoted by (*)). Hence their statistical expected value (denoted by the usual E(•) operator) is also their rational expectation:

(13) $$C_t + \mathrm{E}_t \left(\sum_n C_{t+n} R(n)^{-1} \right) = X_t^{\mathrm{m}} / P_t + \mathrm{E}_t \left(\sum_n (X_{t+n}^{\mathrm{m}} / P_{t+n}) R(n)^{-1} \right)$$

With a labour-only technology and no capital accumulation, it is consistent to characterise a "stationary" SS such that $\mathrm{E}_t X_{t+n} / P_{t+n} = \mathrm{E}_t Y_{t+n} = Y^*$ for all n. Consequently, consumption too should be stationary $C_t = \mathrm{E}_t C_{t+n}$ for all n. According to the Euler equation (see in particular equation (8)) an optimal stationary consumption plan implies that for all future dates $\mathrm{E}_t r_{t+n} = r^* = \theta$. In a stationary

[9] More on the role of net worth in Smith and Wickens (2006, p. 18).

SS, it is also consistent to assume that $E_t\pi_{t+n} = \pi^* \geq 0$ that is a constant inflation rate, so that $i^* = r^* + \pi^*$. Likewise, nominal incomes, too, should grow at the SS inflation rate in order to keep real incomes constant over time. The SS inflation rate should be zero, unless the central bank aims at a positive inflation rate to correct for distortions in the output market. The NK model is usually presented in terms of log-linear deviations of variables from the SS values, to which we shall turn later.

Substituting the previous relationships into (13), we obtain:

(14) $$C_t\left(1+E_t\sum_n R^{*-n}\right) = X_t^m / P_t + Y^* E_t \sum_n R^{*-n}$$

and, for $T \to \infty$,

(15) $$C_t = \frac{r^*}{1+r^*} X_t^m / P_t + \frac{1}{1+r^*} Y^*$$

This is a "true" consumption function, which looks quite different from the underlying Euler equation. Unsurprisingly, it is fully consistent with the well-known Permanent Income Hypothesis (Friedman 1957, Hall 1988). The forward-looking component is given by Y^*, which may be known with certainty or, more generally, as an expected value. As long as *real* incomes are at their SS value Y^* at all dates, the stationary level of consumption is also equal to $C^* = Y^*$ (which ensures the output market-clearing condition). However the *current* consumption at any date t may deviate from C^* to the extent that the *current* real income $X^m{}_t/P_t$ deviates, unexpectedly and temporarily, from Y^*. The coefficient $r^*/(1 + r^*)$ (approximately equal to r^*) gauges the "short-run" marginal propensity to consume.

A key hypothesis in the current foundations of monetary policy is the existence of "nominal rigidities", namely that the prices of all goods, services, and factors are set in terms of money value, *and* are not perfectly indexed with the general price level (Woodford 2003, Galì 2008). Imperfect indexation of nominal values occurs when indexation is not instantaneous (nominal values are revised at fixed dates for a fixed period of time). Therefore, the income effect in the consumption function may originate from two sources: shocks to the nominal income $X^m{}_t$ or to the price level P_t that misalign $X^m{}_t/P_t$ from Y^*. As said above, in SS nominal incomes should grow at the SS inflation rate π^*. Hence, starting in SS, real income in period t will be given by:

(16) $$Y^* \frac{(1+\pi^*)}{(1+\pi_t)}$$

i.e. it will deviate (above, below) its SS value if inflation deviates (below, above) its SS value.

In order to gauge the income effect, let us define $\rho \equiv r^*/(1 + r^*)$, and proceed with the standard method of log-linearization of (15), which yields (see Appendix A1):

(17) $\hat{c}_t = \hat{y}_t = -\rho\hat{\pi}_t$

where $\hat{c}_t$ is the rate of change of consumption, and hence of output (i.e. the output gap) and $\hat{\pi}_t = \pi_t - \pi^*$ is the inflation gap. Hence, an inflationary shock $\pi_t > \pi^*$ depresses consumption and output in proportion to ρ via the income effect.

Up to this point we have found two important implications. First, current consumption, in terms of deviations from SS, depends on unanticipated, temporary shocks to the current real income. Second, this income effect operates even with the real interest rate being at its SS value. What about the role of the policy interest rate?

The answer is less straightforward than looking at the Euler equation alone. In fact, the consumption function (15) is obtained from the consumption budget constraint (13) which is discounted with the expected *future* real interests rate at all dates. Let us consider the case that at date t along the consumption plan an unpredicted change of the policy rate occurs, so that $i_t \neq i^*$. This event modifies the expected one-period-ahead gross real interest rate $E_t R_{t+1} = (1 + i_t)/E_t(1 + \pi_{t+1}) \neq 1 + r^*$, affecting *both* the Euler equation *and* the expected present value of the budget constraint. Then the question is what the rational expectation may be of the future entire sequence of policy rates and inflation rates.[10]

The simplest illustrative case is when it is rational to expect the economy to hover randomly around its SS equilibrium (which may be the case when the central bank's inflation targeting is effective, and policy shocks and inflation shocks follow a random walk), so that it is also rational *not* to expect from t+1 onward any systematic, or predictable, further deviations of the policy rate and the inflation rate from their SS value.

As a result, the consumption function after a policy shock, *ceteris paribus*, can be written in terms of log-deviations from SS as follows (see Appendix A.2):

(18) $\hat{c}_t = -\alpha\left(i_t - i^*\right)$ $\qquad \alpha = (1 - \rho)\eta$

A higher policy rate above i^* depresses consumption according to the elasticity α. This differs, it is lower, than in the standard NK model (η). In fact, the numerator is the complement to the marginal propensity to consume found above

[10] Note that this is the point underlying the policy of "forward guidance" by central banks (Eggertsson and Woodford 2004). The point also highlights the importance of *long-run* expectations, whereas conventional macro-models have concentrated attention on short-run, "one-period-ahead", expectations (Rudd 2021 puts forward criticisms of this modelling habit).

(i.e. it accounts for the marginal propensity to save) and is certainly lower than 1. This ensues from two effects. The substitution effect via Euler equation incentivises to exchange lower C_t (higher saving) for higher C_{t+1}, but the intertemporal budget effect operates in the opposite direction as it increases the future value of consumable resources per unit of saving.[11] For policy purposes one might say that the interest-rate policy is weaker when the marginal propensity to save is lower.

Combining the real income effect of current inflation shocks (17) with the interest-rate effect of policy shocks (18), we obtain the following IS function

(19) $$\hat{y}_t = -\rho\hat{\pi}_t - \alpha\left(i_t - i^*\right)$$

Established this general result, the actual extent of the income effect may come to depend on specific conditions that affect the degree of imperfect indexation of nominal incomes. Most common schemes date back to Taylor's staggered wage contracts (1980), or to extensions of the Calvo firms' pricing scheme to wage setting (Galì 2008, 2013). A common result is that only a fraction of nominal incomes is not indexed at each date.

Let us assume that the fraction γ of contracts are renewed at each date t as in Galì (2013). Indexation introduces two concomitant effects. On the one hand, it offsets the income effect of the inflation surprise. Hence the log-linearized aggregate consumption function results from the fraction $(1 - \gamma)$ of households with not renewed wages and the fraction γ with renewed wages, for which there is no income effect of the inflation surprise, but only the interest-rate effect. Therefore,

(20) $$\begin{aligned} \hat{y} &= -(1-\gamma)\left[\rho\hat{\pi}_t + \alpha\left(i_t - i^*\right)\right] - \gamma\eta\left(i_t - i^*\right) \\ &= -(1-\gamma)\rho\hat{\pi}_t - \left[\alpha + \gamma\eta\rho\right]\left(i_t - i^*\right) \end{aligned}$$

with the consequence that the marginal propensity to consume in response to the inflation surprise is reduced to $(1 - \gamma)\rho$ while the elasticity to the interest rate is greater than α (in other words, the output-gap equation is closer the NK standard one). Yet the income effect of unanticipated inflation is not entirely impaired.

To summarise, the correct elaboration of the consumption function resulting from both the Euler equation and the intertemporal budget constraint, entails two main modifications. The first is the presence of the negative real income effect of current inflation shocks. The second is the reduction of the negative interest-rate effect of policy shocks. This latter may be argued to be quantitatively small, maybe negligible, yet it may turn out to be not-so-negligible for policy purposes over the

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[11] As shown by Smith and Wickens (2006), this countervailing effect is stronger, the higher the initial level of net worth.

business cycle.[12] More importantly, the correct formulation of the IS crucially depends on conditions, and households' information thereof, concerning the entire sequence of the policy rates and the inflation rates at all future dates, and hence how long-run expectations are formed. The analogy between equation (18) and the conventional NK IS results from the specific condition that the policy rate and the inflation rate follow a random walk.

4. Simulations

4.1. The simulation model

This section presents simulations of an empirical three-equations NK model (IS, Phillips Curve, Taylor Rule) inclusive of the income effect of unanticipated inflation as in the IS equation (19). By empirical model it is meant that the microfoundations are not fully explicited while the relevant parameters are set according to the prevailing findings in the literature.

Starting from the model in Appendix A.3, after all the relevant reciprocal interdependencies among the three equations have been worked out, the current inflation gap $\hat{\pi}_t \equiv (\pi_t - \pi^*)$, the current output gap $\hat{y}_t \equiv (y_t - y^*)$, and the policy interest rate gap $\hat{i}_t \equiv (i_t - i^*)$,result as follows (see Appendix A.3 henceforth):

(21) $\hat{\pi}_t = a_1(\pi^e_{t+1} - \pi^*) + a_2 u_{\pi t}$

(22) $\hat{y}_t = b_1(\pi^e_{t+1} - \pi^*) + b_2 u_{\pi t}$

(23) $\hat{i}_t = c_1(\pi^e_{t+1} - \pi^*) + c_2 u_{\pi t}$

where π^e_{t+1} = expected inflation (to be specified), and $u_{\pi t}$ = inflation shocks (for simplicity we consider only inflation shocks), e.g. an unanticipated increase in the nominal unit cost of energy inputs. The coefficients a_n , b_n , c_n (n = 1, 2) are combinations of the parameters of the three equations.

In the standard NK model, with $\rho = 0$, the signs of the coefficients are $a_1 > 0$, $a_2 > 0$, $b_1 < 0$, $b_2 < 0$, $c_1 > 0$, $c_2 > 0$. The necessary and sufficient condition for the system's dynamic stability is $a_1 < 1$, for which a nonzero inflation coefficient in the Taylor rule is necessary ($\phi_\pi > 0$) and the so-called "Taylor principle" ($\phi_\pi > 1$) is sufficient. Then the transmission of an inflation shock $u_{\pi t} > 0$ to the three endogenous variables goes through an increase of the inflation gap (a_2), which triggers an increase of the policy rate (c_2), which feeds back onto the output gap (b_2). This is key to the second round effects on inflation that should eventually close the inflation gap. Notably, $b_2 < 0$ necessarily depends on the reaction of monetary

[12] As a matter fact, recent research has found that the effectiveness of interest-rate policy does change over the business cycle (Schnabel 2020)

policy, i.e. $\phi_\pi > 0$, whereas for $\phi_\pi = 0$, $b_2 = 0$, i.e. inflation shocks have no effect on aggregate demand and output.

A role of their own is played by shocks to expected inflation relative to the target – also known as "de-anchoring" of expectations. This term affects all the three endogenous variables, including the policy rate even though expected inflation may not appear in the Taylor rule explicitly. The transmission channels are similar to the previous one, from opening an inflation gap (a_1), to higher policy rate (c_1) to lower output (b_1). Again, this critical step for the control of the inflation process only depends on the reaction of monetary policy *and* a sufficiently large inflation coefficient in the Taylor rule (the reason being that otherwise higher expected inflation would lower the real interest rate and spur consumption).

As can be seen in the Appendix A.3, the new parameter ρ, which controls for the real income effect in the IS function, modifies the whole set of coefficients (a_n , b_n , c_n). In particular, $\rho > 0$, *dampens* a_1, a_2, c_1, c_2, and *enhances* (greater absolute value) b_1, b_2. These modifications are consistent with the fact that now the inflation shock exerts a direct negative effect on consumption and output (enhanced b_2), which dampens inflation by itself and hence also dampens the response of monetary policy (c_2). The parameter ρ operates analogously in the case of a surge of expected inflation: to the extent that also actual inflation rises, consumption and output fall independently of the reaction on the policy rate.

A key result is that the coefficients *retain the same signs* as in the standard NK model even in the case of neutral monetary policy (i.e. with zero coefficients in the Taylor rule), with the only caveat that for the dynamic stability condition $a_1 < 1$ to hold ρ should exceed a threshold value (see Appendix A.3). This means that active monetary policy is no longer necessary for the stability of the system, but it rather acts as *a complement to the income effect*.

Before proceeding, it is worth noting two features of the reduced-form system (21)-(23). First, the system does not possess intrinsic (endogenous) dynamic forces, but only extrinsic (exogenous) ones, its evolution over time is the one dictated by shocks and expectations. Second, unless shocks and expectations display dynamic instability of their own, the parameter structure of the system ensures dynamic stability around the zero-gaps steady state (also Christiano et al. 2010). We can therefore anticipate that, under these conditions, monetary tightening, alone or in addition to the income effect, can only dampen the dynamic path of the inflationary process. However, whether it is temporary or persistent, reversible or irreversible, is dictated by the shock, and *cannot be modified*.

4.2. Anchored inflation expectations and temporary shocks

For simulations the values of the parameters determining the coefficients a_n, b_n, c_n, have been taken from results commonly found in the empirical literature (see Appendix A.3). The inflation target has been set to 2%. Say that the time unit t is one quarter, and inflation (like other variables) is measured on a year-to-year basis each quarter.

To begin with, let us consider as baseline the "easiest" case in a policy perspective, that is to say one with temporary shocks, anchored inflation expectations and no wage indexation.

The most common definition of anchored expectations is that they are in line with the inflation target and are insensitive to transitory shocks (e.g. Gürkaynak et al. 2010, Fracasso and Probo 2017). These features are easily inserted into our equation (21) by positing that $\pi^e_{t+1} = \pi^*$ independently of the shocks. Therefore,

(24) $\hat{\pi}_t = a_2 u_{\pi t}$

(25) $\hat{y}_t = b_2 u_{\pi t}$

(26) $\hat{i}_t = c_2 u_{\pi t}$

Inflation, output and the policy rate hover around their respective targets as a consequence of the shock. As said above, their co-evolution over time is dictated by the dynamic path of the shock.

The prediction that cost shocks in 2020-21 would have been transitory played a role in the initial response of central banks. To simulate a transitory shock, let us assume a standard autoregressive process:

(27) $u_{\pi t} = \theta u_{\pi t\text{-}1} + \varepsilon_{\pi t}$

where ε_t is a white-noise i.i.d. process and $0 < \theta < 1$.

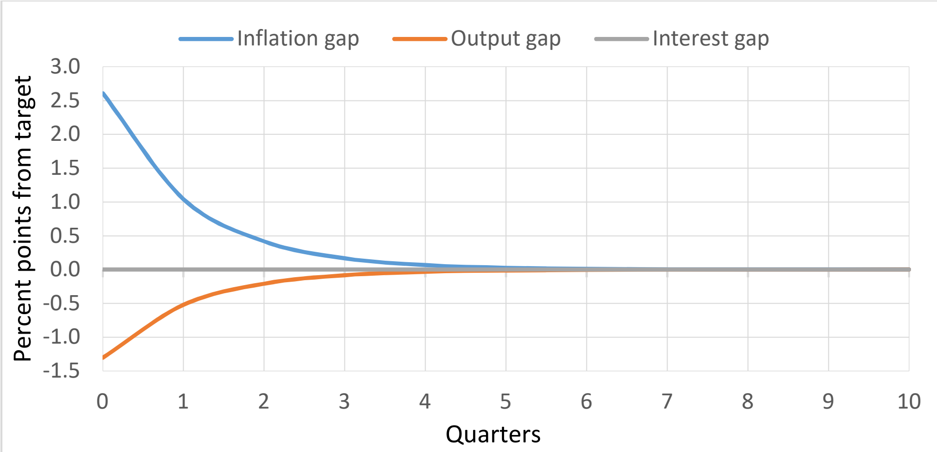
To give some concreteness to the simulations, the initial shock $\varepsilon_{\pi t}$ has been set looking at the difference between the quarterly observations of year inflation in the euro area with respect to earlier forecasts in Table 1. A shock $\varepsilon_{\pi t}$ in the order of magnitude of 3% above anticipations seems a sensible initialisation of our simulations.

To begin with, the shock is assumed to display low persistence, as was initially believed by most central banks, say $\theta = 0.4$ (40% of the previous period's value is left in each next period), which means that 99% of the shock is absorbed in 5 quarters.

Two are the main issues to be examined. The first is how the system behaves when the income effect of the shock operates while monetary policy stands neutral.

Neutral monetary policy has been simulated by setting the Taylor Rule's parameters equal to zero, which implies that the interest gap is nil all the time. Figure 3 shows the paths of inflation and output gaps after the shock.

Figure 3. Paths of inflation and output gaps with income effect and neutral monetary policy



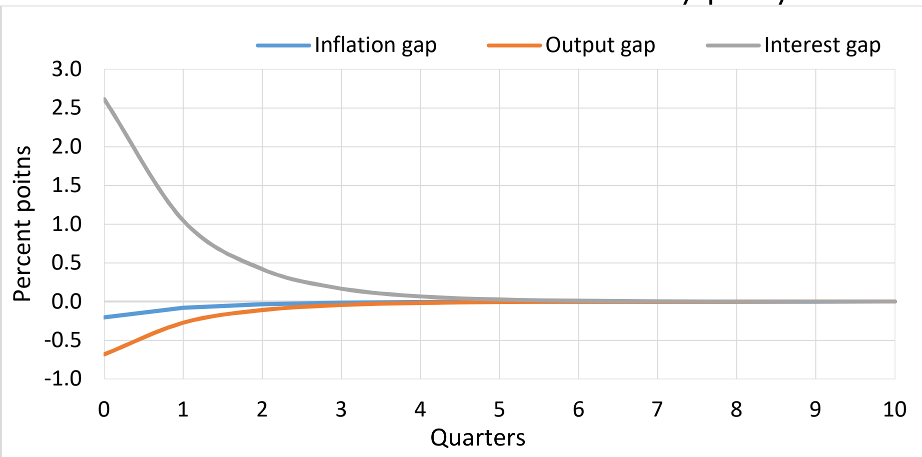
The thrust of the simulation is that, as anticipated above, the inflation shock is reabsorbed even with a neutral policy stance. In the same quarter of the shock the inflation gap rises to 2.61% and subsequently peters out in about 6 quarters. The reason is that the negative income effect of the shock on consumption by itself creates a negative output gap (1.3% on impact) sufficient to curb inflation over time. This scenario seems consistent with the view, expressed by the member of the ECB's Executive Board P. R. Lane, that " Across all available sources, macroeconomic expectations (and prospects at the individual level) suggest a high degree of concern about a potential economic slowdown, a general recognition that supply shocks will generate both near term inflation surges and a decline in the economic outlook, which in turn will constrain the persistence of inflation" (Lane 2022, p. 3).

The second issue is how the system behaves when the income effect operates together with monetary policy (the Taylor Rule's parameters are set to their standard values $\phi_y = 0.5$, $\phi_\pi = 1.5$). Figure 4 tracks the difference between the paths of inflation, output and interest gaps with restrictive with respect to neutral monetary policy (i.e. with respect to Figure 3). On impact, the policy rate is raised by 2.61 points above target. As can be expected, this enhances the fall of aggregate demand and output. The inflation gap is smaller and the negative output gap larger all along the adjustment path. The average reduction per quarter of the inflation gap is 0.1%, *vis-à-vis* an average increase of the negative output gap by 0.31% and of the positive interest-gap by 0.29%.[13] With these data we can compute

[13] Calculation of averages per quarter of each gap is truncated (i.e. convergence to zero is "almost" completed) as the gap falls below 0.5%

the well-known "sacrifice ratio", i.e. the output loss per unit of less inflation, which results 3.1.

Figure 4. Difference between the paths of inflation, output and interest gaps with restrictive and with neutral monetary policy



Three conclusions follow from this exercise. First, stagflation is inherent in any cost-push inflation shock owing to the income effect on households consumption independently of restrictive monetary policy. Second, the economy displays substantial absorption capacity of transitory shocks even with monetary policy remaining neutral, which underpins the anchorage of expectations at least in a medium-long-run perspective. Third, monetary tightening acts as a complement of the income effect enhancing the absorption of the inflation shock at the cost of larger output gaps to an extent that may be dictated by the central bank's preferred adjustment path in favour of smaller inflation gaps.

Beyond this motivation related to their mandate for price stability, the shift to a restrictive monetary policy stance by most central banks is generally predicated in response to less "easy" conditions underlying the inflationary process that may drive the inflation out of control. More or less formally explicited, the threat is one of jumping on a path of dynamic instability. Three factors are closely monitored by central banks: whether shocks display persistence, whether expectations remain firmly anchored to the target, whether a wage-price spiral takes off (Lane 2022, Gopinath 2022).

4.3. Persistent shocks

To begin with the dynamics of the shock, as a matter of fact the sharp increases in energy prices have turned out to be larger and more persistent than initially gauged by central banks as well as by professional operators worldwide (IMF 2022, Chahad et al. 2022).

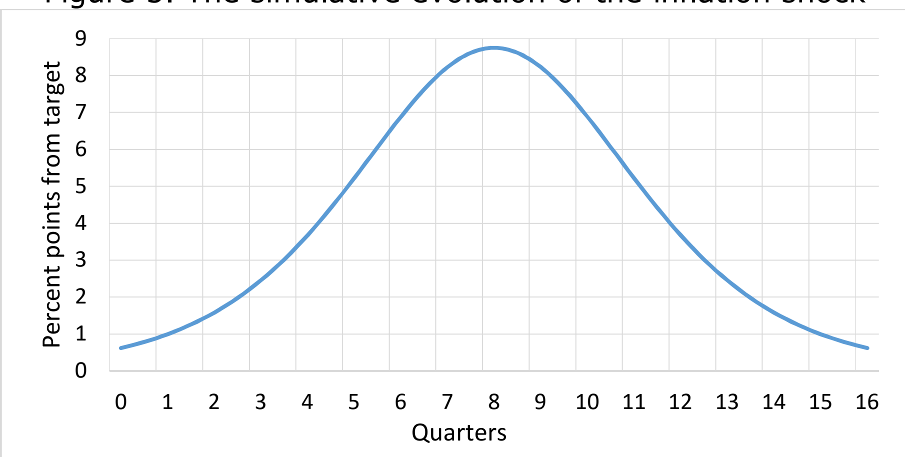
To introduce persistence into the simulation in a way that mimics what is being observed, the inflationary process has been reformulated as a nonlinear epidemic diffusion process. This is a good candidate to capture two features of the global inflation process that are detected by several studies (e.g. IMF 2022, Schnabel 2022, Ball et al. 2022). One is the "contagion" across countries via global commodity markets, the other is the "contagion" from these markets to domestic markets for goods and services classified as "core" in the consumer price indexes. A third feature, which is more a hope for the time being, is that the process initially *accelerates* over time, but then reaches a peak and eventually falls back towards zero.

Epidemic processes may have various mathematical representations, but the above-mentioned essential features can be captured by a bell-shaped logistic equation such as (Baldwin 2020, Baldwin and Weder di Mauro 2020):

$$(28) \qquad u_{\pi t} = S \frac{e^{-\frac{t-\tau}{\delta}}}{\delta\left(1+e^{-\frac{t-\tau}{\delta}}\right)^2}$$

where S is a scale factor, the parameter τ regulates the timing of the peak, and δ regulates the steepness of the process (higher τ determines later peak, higher δ determines less steepness). Setting $S = 70$, $\tau = 8$, $\delta = 2$, $u_{\pi t}$ evolves as in Figure 5, which tracks the annualised exogenous push to the inflation gap, measured each quarter. This process peaks at 8.75% (above target) in eighth quarter and then peters out in the subsequent eight quarters. This seems a sufficiently severe environment.

Figure 5. The simulative evolution of the inflation shock



Examining the implications for the inflation process of this kind of shock *per se*, all else equal, one cannot but replicate what said above about the dynamic properties of system (21)-(23). The inflation process will be driven by the evolution of the shock, i.e. acceleration, deceleration, peak and decline. This kind of shock is not *per se* a source of dynamic instability of system, which will eventually return to the zero-gaps steady state with or without active monetary policy. One important consequence, however, may be serious forecast mistakes. For any *linear* projection of the process at any point along the acceleration phase is bound to underestimate future inflation, while in the deceleration phase it is bound to overestimate it. At the earlier stages whatever you do seems too much, at the later stages whatever you do seems too little (Baldwin 2020; Baldwin and Weder di Mauro 2020).

Of course there exist significant quantitative differences relative to the baseline case. In the eighth quarter the inflation gap peaks at 7.6% with neutral policy and at 7% with active policy, the trough of the output gap is, respectively, –3.8% and –5.45%. With active policy the interest-rate peaks at 7.6% above its reference value with an average gap of 3.6% per quarter, which reduces the average inflation gap by 0.28 points while the average negative output gap is enlarged by 0.93 points. The sacrifice ratio rises to 3.3. As Isabel Schnabel said at the 2022 Jackson Hole conference, in the present inflationary environment "central banks are facing a higher sacrifice ratio" (2022b, p. 6).

4.4. De-anchoring of inflation expectations

With regard to the anchorage of inflation expectations to the target, this is a rather elusive notion, if anything because it overlaps with the distinction between short-run and long-run expectations. As recalled previously, a widely accepted definition is that de-anchored expectations react to macroeconomic news, which seems appropriate for the short-run notion of expectations. Indeed, the standard NK model embodies expected inflation "one period ahead". Applying to the inflation-gap equation (21) the rational expectations hypothesis as the statistical expected value of the data generation process the result would be:

$$\text{(29)} \qquad \mathrm{E}_t(\hat{\pi}_{t+1}) = \frac{a_2}{1-a_1}\mathrm{E}_t(u_{\pi t+1})$$

If the shock follows a random walk, then $u_{\pi t}$ is the best predictor of $u_{\pi t+1}$. If the shock process has some predictable pattern, as is the case in the simulation, this ought to be embodied into the expectation. In any case (short-run) rational expectations would result to be de-anchored.

By contrast, the general opinion is that for the main purpose of keeping inflation aligned with the target long-run expectations matter the most (Rudd 2021, Lane 2022, Gopinath 2022). For instance, in well-established estimation equations of the Phillips Curve (such as Blanchard et al. 2015, Hooper et al. 2019), the expectation term is a weighted average between a measure of long-term and of short-term inflation. Let us call λ the weight of long-term expectations anchored to the target, so that $1 - \lambda$ is the weight of short-term de-anchored expectations. Also, let the latter be quasi-rational, in the sense that, with respect to (29), they seek to track the impact of real time shock $u_{\pi t}$ (e.g. news from the global energy markets) on the inflation gap process:

$$(\pi^e_{t+1} - \pi^*) = a_2 u_{\pi t}$$

Therefore, the inflation gap equation becomes:

(30) $\hat{\pi}_t = a_2(1 + a_1(1 - \lambda))u_{\pi t}$

Clearly, the weight of short-term de-anchored expectations *amplifies* the transmission from the shock to the inflation gap, and hence to the output losses. Still, the dynamics of the inflation gap is dictated by the shock process $u_{\pi t}$ as in the previous cases, and (this kind of) quasi-rational de-anchored expectations do not by themselves generate dynamic instability. If the shock is *reversible*, no matter how long it persists, so the inflation process will be. And again, whether or not monetary policy is neutral only changes the magnitude of the parameters a_1 and a_2 and hence the amplitude of the inflation process. On the other hand, de-anchored expectations further worsen the stagflationary outcome.

May other (less rational?) expectation formation mechanisms be inducive to dynamic instability? Blanchard et al. (2015) proxy the short-term component of expectations by the average of the last four quarters of observed inflation, and estimate λ around 0.5 for the US in the high-inflation period 1975-85.[14] To give more prominence to short-termism and path-dependence, in the simulation the de-anchored expectations take the value of the last observed inflation. Therefore,

(31) $\pi^e_{t+1} - \pi^* = (1 - \lambda)\,\hat{\pi}_{t-1}$

and

(32) $\hat{\pi}_t = a_1(1 - \lambda)\,\hat{\pi}_{t-1} + a_2 u_{\pi t}$

Note that this formulation changes the dynamic structure of the system. Since the inflation-gap becomes a first-order autoregressive process, the weight of de-anchored expectations comes to play a critical role for the stability condition $a_1(1 - \lambda) < 1$ (see also Hooper 2019). However, as long as $a_1 < 1$, this kind of de-anchored expectations certainly contributes to further amplifying the inflation process, but it is not by itself a cause of dynamic instability.

[14] In the subsequent twenty years the estimated λ has constantly risen and then levelled around 0.7.

4.5. Wage-price spiral

Let us now turn to the third main source of concern, i.e. nominal wage indexation or the wage-price spiral. In view of simulation, indexation means that nominal wages are linked to the rate of change of prices in order to keep the real wage unchanged. Therefore, in steady state nominal wages increase at the rate of the target inflation, and what follows should be interpreted as marginal increases proportional to inflation gaps. As already said in section 3, let us follow the most common NK assumption of staggered wage contracts, that is a fraction γ of contracts are renewed at each date t, where $\gamma = 0.25$ as in Galì (2013). On a quarterly basis, this value means that the average duration of contracts is one year, an order of magnitude consistent with evidence. Renewed nominal wages are increased (above trend) by the last observed annual inflation gap in quarter t-1. The result shown in equation (20) is that the marginal propensity to consume in response to the inflation surprise is reduced to $(1 - \gamma)\rho$ while the elasticity to the interest rate is greater than α, i.e. $\alpha + \gamma\eta\rho$.

On the other hand, wage increases are an additional source of cost push proportional to the actual inflation process. The consequence on the Phillips Curve goes through the usual change in the marginal costs (see Appendix A.3). If for simplicity we assume that the unit nominal cost of energy and of labour w^{m} weigh equally in the marginal cost function, we can treat

(33) $$\hat{w}_t^{\mathrm{m}} = \gamma\hat{\pi}_{t-1}$$

as an additional shock to equation (21).

Introducing both the de-anchored expectations (31) and the wage indexation (33), transforms the inflation-gap equation in the following first-order autoregressive process

(34) $$\hat{\pi}_t = (a_1(1 - \lambda) + a_2\gamma)\,\hat{\pi}_{t-1} + a_2 u_{\pi t}$$

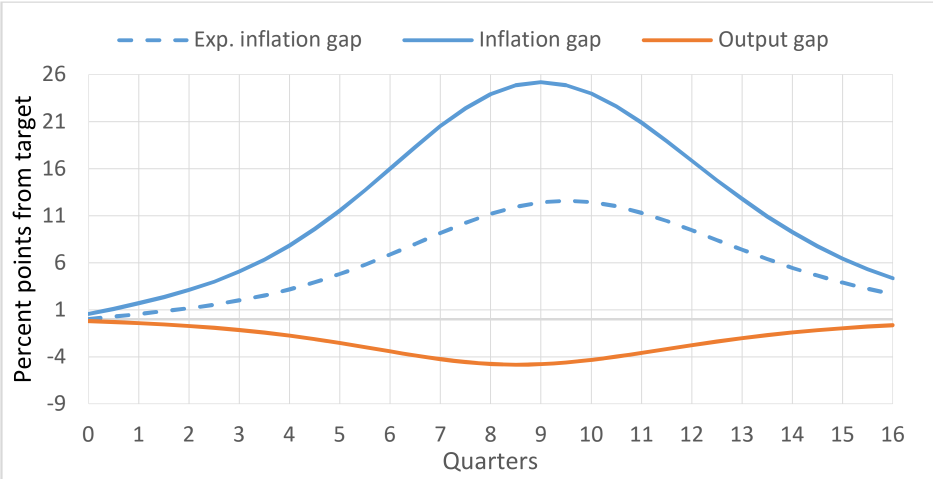
As long as the shock process $u_{\pi t}$ is reversible, key to dynamic stability is only the condition that the autoregressive coefficient is lower than 1. This condition can be thought of as a "frontier" between λ and γ:

(35) $$\lambda \geq -\frac{1-a_1}{a_1} + \frac{a_2\gamma}{a_1}$$

Two are the notable implications. First, the higher the degree of wage indexation, the higher the degree of anchorage of expectations should be; alternatively, lower anchorage requires also lower indexation. Second, as long as the stability condition is fulfilled, it remains true that the system can return to the zero-gaps equilibrium even with neutral monetary policy.

For the parameter values used in the simulation and $\gamma = 0.25$, the stability threshold for λ under neutral monetary policy is 0.21. In fact, for $\lambda = 0.5$ Figure 6 shows that the system still converges to the zero gaps equilibrium as the shock eventually vanishes. Yet, as is easily understood, the more severe conditions make the inflation-gap path much worse.

Figure 6. Paths of inflation, expected inflation and output gaps with income effect, de-anchored expectations, wage indexation and neutral monetary policy

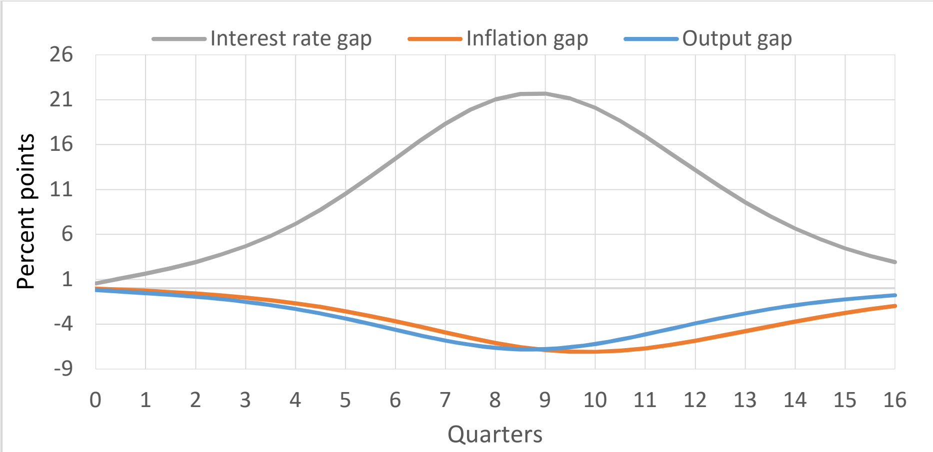


In the first place, the inflation process tracks the same "epidemic" bell-shaped path of the exogenous shock. Secondly, the peak of the inflation gap is slightly delayed relative to the peak of the shock process, and in the ninth quarter is as high as 25.2%, i.e. about three times the peak of the shock. Thirdly converge to (almost) the target (see fn. 13) lasts five more quarters. These are the results of the joint extra-pressure and persistence of the de-anchored fraction of expected inflation, and of the wage indexation, which catches up with actual inflation with one lag. In the ninth quarter an inquiry about the expected inflation gap would record 12.4%, with nominal wages growing at the year rate of 6.2% above trend. Output falls below potential all along the process with the trough at –4.8%. The average values of the gaps per quarter across the process are, respectively, 10.1% for inflation, and – 1.9% for output.

As to the activation of monetary policy, Figure 7 shows that as expected it reduces the inflation-gap all along the process (convergence to the target is also anticipated by three quarters). The policy rate remains above its target value throughout the process by an average amount of 8.6%. The reduction of the inflation gaps amounts to 3% per quarter on average, at the cost of widening the negative output gap by an additional 2.7%. The sacrifice ratio is thus equal to 0.9.[15]

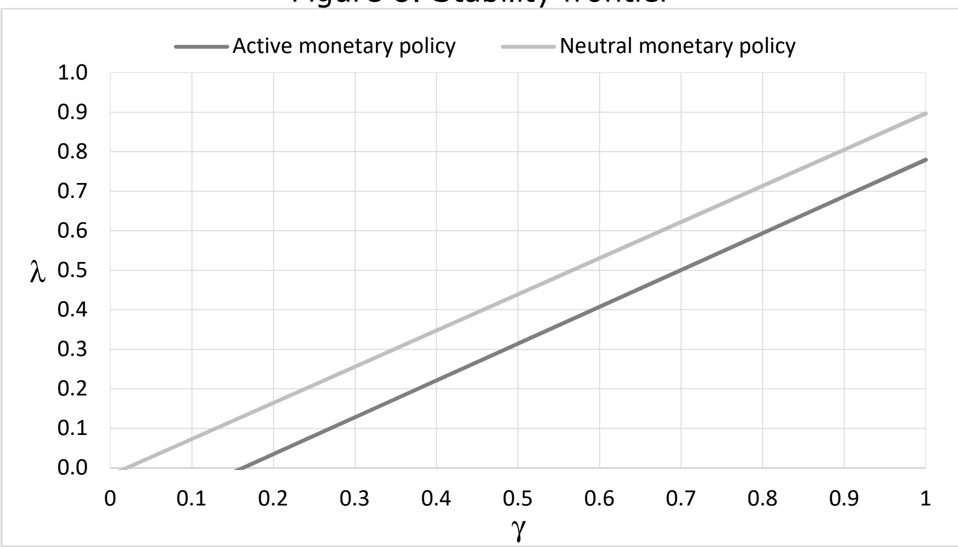
[15] It may be noted that sacrifice ratio is *lower* than in the previous simulations. The reason is that wage indexation reduces the negative income effect of the inflation process while enhances the effect of the policy rate on the process itself.

Figure 7. Differences of paths of inflation, interest-rate and output gaps with active with respect to neutral monetary policy



However, there is now another relevant consequence. Since the activation of monetary policy lowers a_1, a_2 (the impact of expectations and of the shock on inflation), beside dampening the inflation process it *relaxes the stability frontier* (less expectation anchorage is necessary for any given wage indexation, or higher wage indexation is allowed for any given expectation anchorage). Figure 8 shows the stability frontier (35) with neutral and active monetary policy.

Figure 8. Stability frontier



Stability occurs for parameter combinations that lie north-west to the respective frontiers. As can be seen, the empirical values $\lambda = 0.5$ and $\gamma = 0.25$ used in the simulations are compatible with stability under both policy regimes. Note however that, given $\gamma = 0.25$, the stability threshold for λ is (at least) 0.21 with neutral monetary policy but is relaxed to (at least) 0.08 with active monetary policy. Alternatively, given λ= 0.5, the stability threshold for γ is (no more than) 0.58 with neutral monetary policy and (no more than) 0.7 with active monetary policy. As a consequence, a corridor exists where the system is stable under active policy but not under neutral policy.

In *this* context, in a system that *may become unstable endogenously*, restrictive monetary policy does become essential in order to enlarge the parameter space where the system remains dynamically stable.

5. Conclusions

At the centre of the ongoing consensus forecasts of global growth slowdown there lies the "cost-of-living crisis" (IMF 2022) created by the post-pandemic inflation shock *vis-à-vis* nominal incomes lagging behind. This paper's aim was to address the theoretical puzzle that the dominant NK framework for policy analysis contains no transmission channel between an inflation surprise and lower output, except a monetary restriction that increases real interest rates substantially, which is not (yet) observable in the data. This role of monetary policy is also deemed necessary in order to warrant the dynamic stability of the economy.

The origin of this puzzle is due to the lack of a proper consumption function. The NK IS reproduces the substitution effect on consumption of changes in the real interest rate, but it misses the real income effects due to shifts of households' intertemporal budget for a given real interest rate. The reason for this oddity is that in the NK model households' intertemporal budget constraint is not explicited.

Upon reformulating the NK IS with a "true" consumption function derived from households' optimal intertemporal consumption plan under their budget constraint, the IS displays *both* the usual substitution effect in relation to the real interest rate *and* an income effect due to unanticipated shocks to current real income, a cause of which may be an inflation surprise. The key theoretical consequence is that the role of Taylor-ruled monetary policy is no longer necessary for the system to be dynamically stable.

Simulations reproducing different, "softer" and "harder" scenarios dependent on different dynamic specifications of the inflation shock confirm that it can be reabsorbed through its income effect restraining demand and output even with monetary policy standing neutral. Monetary tightening operates as a complement to the income effect to dampen the inflation process at the expense of larger negative output gaps, as may be dictated by the central bank's mandate, but the intervention of monetary policy is no longer essential for convergence to the target.

Do these findings mean that current motivations of central banks for taking resolute actions to curb inflation and prevent dynamic instability are groundless? Certainly not. History teaches that inflation processes can indeed get out of control. What this paper has shown is that, and how, the standard NK model *should be modified* for *dynamic instability to be created endogenously*, by way of a critical combination of path dependent de-anchored inflation expectations with indexed wages. This is the case when Taylor-ruled monetary policy does become essential in order to enlarge the corridor where the system remains dynamically stable.

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Appendix A.1

For any variable Z_t, define $\hat{Z}_t \equiv Z_t/Z^*$ its deviation ratio from its SS value Z^*. The deviation rate is $\hat{z}_t = \hat{Z}_t - 1$, and, if "sufficiently small", it can be approximated by the natural logarithm $\hat{z}_t \approx \ln \hat{Z}_t = \ln X_t - \ln X^{ss}$. Consequently, by approximation it is also possible to write,

(A1) $Z_t \approx Z^* e^{\hat{z}_t} = 1 + \hat{z}_t$

Let us consider the consumption function (15) in the case of an unanticipated temporary shock to the current inflation at date t. The effect on the current real income $X^m{}_t/P_t$ is given by (16); therefore:

(A2) $$C_t = \frac{r^*}{1+r^*}\frac{1+\pi^*}{1+\pi_t}Y^* + \frac{1}{1+r^*}Y^*$$

Defining $\rho \equiv r^*/(1 + r^*)$ and $\hat{\pi}_t \equiv \pi_t - \pi^*$ (inflation gap), the deviation rate of consumption is approximated as follows:

$$C^* e^{\hat{c}_t} = \rho Y^* e^{-\hat{\pi}_t} + (1-\rho)Y^*$$

(A3) $C^*(1+\hat{c}_t) = \rho Y^*(1-\hat{\pi}_t) + (1-\rho)Y^*$

Since $C^* = Y^*$, the result is equation (17) in the text

(A4) $\hat{c}_t = \hat{y}_t = -\rho\hat{\pi}_t$

Appendix A.2

Let us formulate the log-linear approximation of deviations of the intertemporal budget constraint (13) from SS values as a consequence of changes in the sequence of real interest rates while keeping all other variables at their SS value:

(A5) $C^* e^{\hat{c}_t} + \mathrm{E}_t \sum_n C^* e^{\hat{c}_{t+n}} D^*(n) e^{\hat{d}(n)} = Y^* + \mathrm{E}_t \sum_n Y^* D^*(n) e^{\hat{d}(n)}$

where $D^*(n) \equiv (1+ r^*)^{-n}$ is the SS real discount factor at $t+n$, $n = 1, \ldots, T$.

In this expression, $\hat{c}_t, \ldots, \hat{c}_{t+n}, \ldots$ denote log rates of change in the intertemporal allocation of consumption (via Euler equation), and $\hat{d}(n)$ log rates of change in the real discount factors at each future date n, which also affect the PV of consumable resources.

The case treated in the text is an unanticipated change in the policy rate at date t, $i_t \neq i^*$ which modifies the one-period-ahead gross real interest rate $\mathrm{E}_t R_{t+1} = \mathrm{E}_t(1 + i_t)/(1 + \pi_{t+1}) \neq 1 + r^*$, and hence the discount factor $D(1)$, all other variables being unchanged. Therefore,

(A6) $$\begin{aligned} &C^*(1+\hat{c}_t) + \mathrm{E}_t C^* D^*(1)(1+\hat{c}_{t+1})\left(1+\hat{d}(1)\right) + \mathrm{E}_t \sum_n C^* D^*(n+1) = \\ &= Y^* + \mathrm{E}_t Y^* D^*(1)\left(1+\hat{d}(1)\right) + \mathrm{E}_t \sum_n Y^* D^*(n+1) \end{aligned}$$

Expanding the t+1 components on both sides, and setting $\hat{c}_{t+1}\hat{d}(1) \approx 0$, (A6) simplifies to:

$$C^*\hat{c}_t + C^* + \mathrm{E}_t\sum_n C^*D^*(n) + \mathrm{E}_t C^*D^*(\hat{c}_t + \hat{d}(1)) =$$
$$= Y^* + \mathrm{E}_t\sum_n Y^*D^*(n) + \mathrm{E}_t Y^*D^*\hat{d}(1)$$

Since $C^* = Y^*$, taking the limit as $T \to \infty$, we obtain

(A7) $\hat{c}_t + (1+r^*)/r^* + \mathrm{E}_t(\hat{c}_{t+1} + \hat{d}(1))/(1+r^*) = (1+r^*)/r^* + \mathrm{E}_t(\hat{d}(1))/(1+r^*)$

As said above, $\hat{c}_{t+1}$ is the $(t, t+1)$ log rate of change of the optimal intertemporal allocation of consumption. Using Euler equation (9), and the SS condition $r^* = \theta$,

$$\mathrm{E}_t\hat{c}_{t+1} = \mathrm{E}_t\ln C_{t+1} - \ln C_t = -\mathrm{E}_t\ln\left(\frac{1+r^*}{(1+i_t)/(1+\pi_{t+1})}\right)^{1/\sigma} =$$
$$= \sigma^{-1}(i_t - \mathrm{E}_t\pi_{t+1} - r^*)$$

Likewise

$$\mathrm{E}_t\hat{d}(1) = \ln\left(\frac{\mathrm{E}_t R_{t+1}}{R^*}\right)^{-1} = \left[\frac{\mathrm{E}_t\left((1+i_t)/(1+\pi_{t+1})\right)}{1+r^*}\right]^{-1} =$$
$$= -(i_t - \mathrm{E}_t\pi_{t+1} - r^*)$$

Substituting these values into (A7), the final result is

(A8) $\hat{c}_t = -((1+r^*)\sigma)^{-1}(i_t - \mathrm{E}_t\pi_{t+1} - r^*)$

If $\mathrm{E}_t\pi_{t+1} = \pi^*$, since $r^* + \pi^* = i^*$, and $(1 + r^*)^{-1} = 1 - \rho$, equation (18) in the text is obtained

(A9) $\hat{c}_t = -\alpha(i_t - i^*)$ $\qquad\qquad \alpha = (1 - \rho)\eta$

Appendix A.3

The standard NK model for policy analysis consists of three equations determining at each date t, respectively, the level of inflation (Phillips Curve (A9)), the level of output (IS equation (A10)), and the policy rate (Taylor Rule (A11)). The three equations are usually expressed as log-rates of deviation form their SS values (or more commonly as "gaps").[16] The IS equation is modified to include the income effect of unanticipated inflation as a deviation from the central bank's target as in equation (19) in the text. In the baseline model for simulation it is assumed zero wage indexation ($\gamma = 0$). Therefore,

(A9) $\quad \pi_t = \beta\pi^e{}_{t+1} + \kappa(y_t - y^*) + u_{\pi t}$

(A10) $\quad y_t = y^* - \rho(\pi_t - \pi^*) - \alpha(i_t - i^*)$

(A11) $\quad i_t = i^* + \phi_\pi(\pi_t - \pi^*) + \phi_y(y_t - y^*)$

The inflation shock $u_{\pi t}$ can be interpreted as an unticipated increase in the unit price of any variable input (e.g. energy as well as labour), according to the following considerations. The NK PC is commonly derived as the log-linear combination at date t of the fraction of monopolistically competitive firms that reoptimise their

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[16] For a reference treatment see Galì (2008).

price-quantity decision for any observed shock, and the complementary fraction of those who do not (the latter fraction is thus a measure of the "price stickiness" in the system).

The basis of the optimal pricing decision is the equality between marginal revenue and marginal cost, leading to the standard result of the supply price exceeding the marginal cost by a "mark up" which is a function of the elasticity of demand. Changes in the unit price of any variable input are thus transferred to the supply price taking into account the elasticity of demand and the technical coefficient of the input in the production function.

For precision, therefore, the shocks $u_{\pi t}$ might be weighed by a parameter (as is the case with the output gaps), depending on the specific characteristics of the demand function, the production function, and on the fraction of optimising firms. Disregarding this quantitative detail, however, does not affect our treatment in an essential manner.

The reduced form of the three equations is given by the system (21), (22), (23) in the text, which is reproduced here for convenience

$$\hat{\pi}_t = a_1(\pi^e_{t+1} - \pi^*) + a_2 u_{\pi t}$$
$$\hat{y}_t = b_1(\pi^e_{t+1} - \pi^*) + b_2 u_{\pi t}$$
$$\hat{i}_t = c_1(\pi^e_{t+1} - \pi^*) + c_2 u_{\pi t}$$

The coefficients a_n, b_n, c_n $(n = 1, 2)$ have the following expressions:

$$a_1 = [\beta(1 + \alpha\phi_y) + \alpha\kappa]A,\ a_2 = (1 + \alpha\phi_y)A$$
$$b_1 = [\alpha - \beta(\rho + \alpha\phi_\pi)]A,\ b_2 = -(\rho + \alpha\phi_\pi)A$$
$$c_1 = [\alpha(\kappa\phi_\pi + \phi_y) + \beta(\phi_\pi - \rho\phi_y)]A,\ c_2 = (\phi_\pi - \rho\phi_y)A$$
$$A = [1 + \alpha(\kappa\phi_\pi + \phi_y) + \rho\kappa]^{-1}$$

Following the now standard solution method of the three-equation system as e.g. in Bullard and Mitra (2002)[17], the necessary and sufficient condition for the system's dynamic stability is $a_1 < 1$. In the standard case with $\rho = 0$, it is necessary that

$$\phi_\pi > 1 - \frac{(1-\beta)(1+\phi_y\alpha)}{\kappa\alpha}$$

for which $\phi_\pi > 1$ is sufficient. In the case with $\rho > 0$, dynamic stability still holds under neutral monetary policy ($\phi_\pi = \phi_y = 0$), provided that

$$\rho > \alpha - \frac{1-\beta}{\kappa}$$

The parameter values have been set as follows.

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[17] In their treatment the potential output y^* also appears as an exogenous expectational variable. This modification would not affect the results presented herein.

- α. Direct econometric estimates of the elasticity of expenditure to the interest-rate gap yield lower values between 0.2 and 0.3 (e.g. Smets and Wouters 2003; Laubach and Williams, 2003; Garnier and Wilhelmsen, 2005). Hence its value has been set at $\alpha = 0.3$.
- r^*, β . According to the NK standard model, the equilibrium value of the natural rate is $r^* = 1/\beta - 1$. The consensus value $r^* = 2\%$, dating to the original specification of the Taylor Rule (Taylor, 1993), yields the commonly used value of $\beta = 0.98$.
- κ. Calibration of the slope of the PC κ in NK models yields very low values. For instance, a common order of magnitude of firms not adjusting prices in the face of shocks is around 75% (e.g. Smets and Wouters 2003, Luk and Vines 2015); then, the Calvo equation with $\beta = 0.98$ yields $\kappa = 0.09$. Direct econometric estimates of the slope of the PC equation over the last decades typically provide higher values, in the range of 0.5. However, after Blanchard et al. (2015), various works have produced evidence of "flatter" PC, with κ falling between 0.2 and 0.3. More recent works, mostly based on European data, find a "steepening" of the PC in the aftermath of the Great Recession (e.g. Riggi and Venditti 2014, Bank of Ireland 2014, Oinonen and Paloviita 2014), with the estimated slope around 0.4. A mid value among these estimates has been chosen, i.e. $\kappa = 0.3$.
- ϕ_y, ϕ_π. The Taylor Rule parameters have been set according to the usual benchmark of Taylor's (1993) original empirical model, $\phi_y = 0.5$, $\phi_\pi = 1.5$.
- ρ. Relevant to the present model is the marginal propensity to consume in the face of unanticipated changes in current (real) income (see e.g. Jappelli and Pistaferri 2010 for the distinction between anticipated and unanticipated changes). Moreover, it is also consistent with this study's aims to focus on the EA. Drescher et al. 2020 is an up-to-date paper that surveys the evidence and provides further cross-country evidence. Looking at the range of values found in this paper (from 0.37 for the Netherlands to 0.4 in Italy to 0.57 in Lithuania) 0.5 seems a sensible parametrisation. According to equation (18) in the text, $\alpha = (1 - \rho)\eta$. The chosen values of $\alpha = 0.3$ and $\rho = 0.5$ imply $\eta = 0.6$. This value is in line with calibrations of consumers' intertemporal elasticity of substitution common in the Real-Business-Cycle literature, which typically converges on values between 0.5 and 1. Form this point view, the parameter ρ plays a role analogous to the parameter of external habit formation in consumption in Smets and Wouters (2003, equation 38).

With these parameter values, the condition for dynamic stability under neutral monetary policy is $\rho > 2.33$, which is satisfied. As a result,

	Standard case ρ = 0	Neutral monetary policy, ρ = 0.5	Active monetary policy, ρ = 0.5
a_1	0.95	0.93	0.85
a_2	0.89	0.87	0.80
b_1	-0.11	-0.17	-0.44
b_2	-0.35	-0.43	-0.66
c_1	1.37	0.00	1.05
c_2	1.17	0.00	0.87