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How to cope with the effective lower bound and a low neutral rate: a comparison of alternative monetary policy strategies

Alessandra Locarno

Abstract

In the last decade, the growth performance has been disappointing and inflation has remained below its desired value for a long period of time, notwithstanding the efforts of central banks to provide as much stimulus as possible. Large enough financial shocks and the trend decline in interest rate have reduced the effectiveness of standard monetary policy. A low level of the natural rate of interest increases the probability of hitting the ELB: a skilful steering of expectations becomes essential to restore the effectiveness of central banks' actions; in this respect, inflation targeting seems lacking. The objective of this research is to provide empirical evidence that strategies like price-level targeting or average inflation targeting are in several respects more effective in stabilising output and inflation and in reducing the frequency of ELB episodes. These alternative monetary policy strategies seem able to outperform inflation targeting even with a higher inflation objective.

1. Introduction

Is inflation targeting is an idea past its sell-by date? The research question I attempt to answer is what strategy is most likely to be effective in response to the decline of the natural rate of interest and the resulting increased probability of hitting the zero lower bound (ZLB) of monetary policy interest rates. This issue is particularly relevant since at the ZLB it is impossible for the central bank to use the primary policy instrument, the short-term interest rate, to manage aggregate demand and control inflation. Unconventional measures, although used extensively in the aftermath of the global financial crisis, have unclear effects on the economy and, according to some, their effectiveness is inversely related to their use. Thus, academics and central bankers are now evaluating the best way to avoid that ZLB episodes occur too frequently.

In Section 2, I describe the main challenges facing monetary policymakers in the current economic environment characterised by a flat Phillips curve and low natural rate of interest.

The third section presents a review of alternative monetary policy strategies proposed in the economic literature in order to cope with the effective lower bound. In the fourth section, I present a New Keynesian model in order to assess the effectiveness of different monetary policy strategies (inflation targeting, price-level targeting and average inflation targeting) carried out under discretion. The current inflation targeting regime is used as a benchmark to evaluate the different proposals. The performance of each strategy is evaluated on the basis of two main criteria: 1) the variability of inflation, the output gap and the monetary policy interest rate, and 2) the ability to reduce the incidence of the zero lower bound. Section 5 and 6 present respectively, robustness checks and a different variant of the baseline case.

2. Challenges for monetary policy

The global financial crisis (GFC) led central bankers to rethink how monetary policy should be conducted. It is a widespread view that the design of a "New Normal" needs to take into account not only the lessons learnt from the crisis but also the steady decline in the natural interest rates and the worsening of the output-inflation trade-off (Brainard, 2017).

The natural rate of interest - whose concept was introduced for the first time by Knut Wicksell in 1898 - can be defined as "*the real short-term interest rate consistent with output equalling its natural rate and constant inflation*" (Holston *et al.*, 2016). This rate of interest has declined over the past two decades and across all the major advanced economies, reaching historically low levels in the aftermath of the global financial crisis.

Even if the measurement of the natural interest rate is very challenging, numerous studies estimated its sizable decline in many advanced economies, using different methodologies. According to the estimates of Laubach and Williams (2016), the natural rate of interest, which was about 2% before the crisis in the US, has become slightly negative in 2017. Holston, Laubach and Williams (2016) estimated the natural interest rates not only for the United States but also for Canada, the Euro Area and the United Kingdom, showing that all countries have experienced a "moderate secular decline" in the period 1990-2007 and a stronger reduction over the last decade.

Many factors have contributed to driving down the natural interest rate and many of them are global rather than country-specific (Laubach and Williams, 2016); the main ones are:

1. demographic developments, such as lower fertility rates, longer life expectancy and the increase in the dependency ratio, which affect the natural rate of interest through shifts in savings preference and lower economic growth;
2. income inequality, which affects the savings ratio and possibly human capital accumulation, putting downward pressure on the neutral rate;
3. the global saving glut, i.e. an excess of savings in particular in emerging economies;
4. the shortage of safe assets, which translates into increasing premia for liquidity and safety;
5. lower trend growth and secular stagnation, due to either supply-side or demand-side factors.

The first four factors tend to increase desired savings, resulting in a rightward shift of the savings curve. Through a savings-investment framework, an increase in savings preferences translates into a lower level of the natural rate of interest, since this rate is equivalent to the real interest rate, i.e. the price of future consumption expressed in terms of consumption today. The last factor instead affects both the savings and the investment curve.

These different sources of the fall in interest rates could be overlapping in explaining the fall in the natural rate of interest. Predicting its future path depends heavily on the main causes of its decline.

The concept of the real equilibrium interest rate is very important because it provides a benchmark for defining the stance of the monetary policy: contractionary if the policy interest rate is above the natural rate and expansionary if it is below. Because of the existence of the zero lower bound (ZLB)[1], too low a neutral interest rate limits the effectiveness of standard monetary policy: the lower the level of the natural rate, the narrower the space available for cutting the policy rate to stabilise aggregate demand and thereby the higher the frequency and duration of periods when the policy rate is constrained by the effective lower bound (ELB) (Fisher, 2016; Constâncio, 2016; Blanchard, Dell'Ariccia, and Mauro, 2010; Summers, 2014).

The ability of monetary policy to reach its objectives is further complicated by the flattening of the Phillips curve observed in many advanced countries, which makes wages and inflation less responsive to the economic slack. In G7-economies the correlation between unemployment and changes in inflation has become much weaker since 1995-1996, reaching nearly zero after the Great Recession. This means that, on average, inflation can remain subdued even for historically low levels of the unemployment rate. There is no consensus about the factors that have determined this flattening. Some scholars identify explanations in the greater effectiveness of monetary policy in the anchoring of inflation expectations (Laxton and N'Diaye, 2002; Kiley, 2008; Boivin, Kiley and Mishkin, 2010), or in the high degree of nominal price stickiness (Ball and Mazumder, 2015). Other academics find an explanation in the increasing importance of the role of external supply shocks, such as globalisation (IMF, 2006; Guillox-Nefussi, 2015), or in the reduction of the bargaining power of workers (Hawksworth and Durnham 2017).

The uncertainty about determinants of the flattening of the Phillips curve does not allow to fully assess its policy implications, which are strictly linked to its underlying causes. Irrespective of its origin, the flattening of the Phillips curve implies a certain loss of information and, even more importantly, it makes monetary policy-making more difficult, as it weakens the transmission of monetary policy impulses, making inflation and output more volatile.

The global financial crisis has exposed the major weaknesses of the inflation targeting regime currently adopted by the central banks of most advanced economies. Although inflation targeting has

[1] The terms zero lower bound (ZLB) and effective lower bound (ELB) are used here interchangeably.

proved to be very successful since its introduction in the 1990s, when inflation was high and volatile, nowadays it faces a wave of criticism, which brings into question, in particular, its ability to fight severe recessions. In contrast to the situation in the early 1990s, the problem is now that inflation is too low, as many countries are undershooting, rather than overshooting, their targets. This is a direct result of the deep recession triggered by the global financial crisis, which pushed monetary policy rates to the zero lower bound and has been keeping inflation consistently below target for long.

3. Literature Review

The likelihood of hitting the zero lower bound is much higher than previously thought, because of the decline in the natural rate of interest. Accordingly, there will be less room for manoeuvre for standard monetary policies in future recessions and hence their persistence and depth are likely to worsen. For this reason, there has been much discussion lately on whether inflation targeting (IT) still is the right way to go. There seem to be two different schools of thought on the matter: evolution or revolution. The first suggests that the inflation target should be raised, while the second advocates a change in regime and calls for a price-level target. In between these two schools of thought, lies the proposal put forth by Nessén and Vestin (2005) who advocate average inflation targeting.

Raising the inflation target may appear like the simplest solution to prevent a higher incidence of the ZLB, as it would not require a radical change of the monetary policy framework and it would be easily communicated to the public. Those who advocate such a solution state that there has never been a clearly optimal inflation target, thus clinging to a 2% target, now perceived as too low, is not advisable.

Ball (2013) estimated the risk of zero-bound episodes in the US by analysing the behaviour of interest rates in past recessions and showed that a higher inflation target could be beneficial as it would lower the probability of incurring a liquidity trap. The 4% inflation target proposed by Ball would imply that in the past the ZLB constraint would have been binding only in 2 recessions out of 8, instead of the 4 cases out of 8 resulting from the current 2% target.

Another argument in favour of raising the inflation target is given by downward nominal rigidities, i.e. the fact that workers' nominal compensation is rarely reduced as wage cuts are unpopular both to employers and employees. Downward wage rigidity is particularly relevant in the current low inflation environment because it prevents real wages to adjust as much as needed to keep unemployment low (Krugman, 2014). A higher inflation target would allow employers to cut real wages without affecting nominal ones, thus reducing involuntary unemployment.

However, inflation has costs that should be thoroughly assessed before deciding to adopt a higher target. Some of the main concerns associated with a higher inflation target regard inflation variability and price dispersion. Inflation variability seems to be positively correlated with higher inflation and so does price dispersion, which lowers welfare through inefficient allocation of resources. Another major risk in raising the target is jeopardizing the credibility of central banks since one of the greatest achievements in monetary policy is the anchoring of inflation expectations around 2%. Ascari and Sbordone (2014) provide a detailed analysis of the problems generated by higher trend inflation, which results in a lower level of steady-state output (and thus welfare), a flatter Phillips curve and a less effective monetary policy.

Unfortunately, neither the benefits nor the costs of a higher inflation target have been clearly and unambiguously quantified in the literature, making it hard to assess whether a target of 4% would be beneficial or detrimental to society's welfare. It is noteworthy to point out that the costs of a higher target are permanent so that even if they are small in any given year, they add up. Bernanke (2017), for example, while acknowledging that this proposal has some merits, adds that it is not the most effective way to deal with the ZLB problem. Nonetheless, this suggestion has gained a foothold in the aftermath of the crisis (Yellen 2017).

Rather than fixing inflation targeting, some authors have proposed to do without it. A departure from inflation targeting was proposed prior to the crisis: Woodford (2003) argued that the optimal policy under commitment, which exhibits history-dependence, can be implemented by targeting the price level (PLT) or, to a lesser extent, nominal GDP.

The first author who questioned the superiority of IT over PLT and especially the notion that there is a trade-off between long-term price level variability and short-term inflation variability was Lars Svensson in 1999. The common view at that time was that the trade-off was due to the history-dependence of price-level targeting: history-dependence implies that if the price target was overshot in the past, it must be undershot in the future (and the other way around) in order to bring back the price level to its desired value. This generates higher inflation variability than under IT and it also entails higher output variability if nominal rigidities are present. Svensson instead proved that in a backward-looking New Classical model satisfying certain conditions, it is indeed possible to improve inflation variability without worsening that of output. According to Svensson, if the model displays significant output persistence, under discretion PLT uniformly dominates IT by improving the trade-off between inflation and output gap variability. PLT is superior even when judged on the basis of a loss function that depends on inflation, not the price level. The possibility that PLT with sufficient output persistence reduces inflation volatility without worsening output gap volatility appears to be a sort of "free lunch", as suggested in the title of Svensson's paper (1999).

Vestin showed that these findings hold in a forward-looking New Keynesian model as well. In Vestin's paper (2000) the output gap is driven by expected future inflation (the forward-looking aspect of monetary policy) and not by inflation surprises, as in Svensson (1999). The central bank uses the output gap as an instrument and is, once again, unable to commit "*in the strict sense of not being able to credibly announce future actions inconsistent with the assigned loss function*". IT under commitment solution is here taken as a benchmark to evaluate the two alternative policy regimes (IT under discretion and PLT).

Vestin finds that PLT is in general very close to the commitment solution, the more so when the persistence of the cost-push shock is low. The reason why PLT is more effective in reducing the trade-off between the variability of inflation and of the output gap is precisely that it exhibits history dependence, which allows the central bank not only to affect the output gap but also inflation expectations.

The fact that price level targeting is similar to and, under certain conditions, coincides with the commitment solution is not too surprising. Woodford (2003), for example, states that policy under commitment is optimal because it entails history dependence "*because the anticipation by the private sector that future policy will be different as a result of conditions at date t [..] can improve stabilisation outcomes at date t*". Thus, a history-dependent policy can tame inflationary pressure with less contraction of output.

Eggertson and Woodford (2003) identified a PLT regime, either with a time-varying or a fixed target, as an optimal policy. Price-level targeting, by committing to undo any deflation with subsequent inflation, has a built-in automatic stabiliser that an inflation targeting regime does not possess. This feature is particularly useful when the natural rate of interest is low, as currently is. Needless to say, it is important that the strategy is well understood by the public and so the central bank has to be very careful in communicating its objectives and targets.

With the Great Recession, the ZLB stopped being only a theoretical concern and became a potential threat. John Williams, President of the New York Fed was one of the early supporters of price-level targeting and is now advocating a serious evaluation of alternative monetary policy frameworks that could supplant inflation targeting (2019).

Recently, a milder version of price-level targeting has been proposed by Bernanke (2017), who suggests resorting to the implementation of a temporary PLT strategy only in periods when conventional policies are constrained by the zero lower bound: the standard practice of targeting inflation would be maintained in normal times while a makeup policy would be adopted in periods when inflation is persistently below target.

In conclusion, a large strand of the literature identifies price-level targeting as the optimal policy at all times, but particularly when a liquidity trap prevents interest rate policies to provide the degree of accommodation needed to stabilise the economy.

In 2005, Nessén and Vestin proposed an alternative strategy, named average inflation targeting, which lies in-between price-level targeting and inflation targeting. It exhibits some degree of history dependence and is sufficiently similar to the current policy framework. They found that such a strategy may outperform both PLT and IT when price setters' behaviour is relatively backward-looking.

Nessén and Vestin define average inflation targeting (AIT from here on) as *"a policy where the central bank's objective is to keep average inflation measured over several years stable"*. The main difference from inflation targeting is that the central bank does not need to reach the inflation target in one period, but instead needs to keep on target inflation averaged over a given horizon. This implies that AIT displays history dependence, though less extensively than PLT.

Vestin (2000) proved that in a forward-looking model PLT is superior to inflation targeting. Nessén and Vestin (2005) extended this analysis to include average inflation targeting and sought to assess how it measured up to the other two regimes. They found that under discretion PLT is superior to both inflation targeting and average inflation targeting but AIT dominates IT.

4. Simulation evidence on alternative monetary strategies

The literature surveyed in the previous section found that under discretion price level targeting is superior in normal times to inflation targeting in: (i) a backward-looking New Classical model with significant output persistence ($\rho > 0$) and (ii) in a forward-looking New Keynesian model. In the latter case, in particular, PLT replicates the equilibrium achieved by IT under commitment when there is no persistence in the cost-push shock.

I will try and assess whether the superiority of PLT over IT and other monetary policy strategies holds in a New Keynesian model in which endogenous persistence is present in the Phillips and IS curves. I analyse via simulations the effectiveness under discretion of a few different monetary policy strategies: (i) the current IT regime; (ii) IT with a higher inflation objective; (iii) PLT; (iv) AIT. For the last strategy, I evaluate the performance of both an 8-period AIT and a 12-period AIT, which corresponds to the average of inflation taken over 2 and 3 years respectively, in order to capture different degrees of history dependence. Finally, inflation targeting under commitment is used as a reference to the best outcome that can be achieved.

The performance of each strategy is evaluated on the basis of two main criteria: 1) a linear combination of inflation and output gap variability (and, in the next section, the interest rate variability as well), with weights that reflect society's preferences, and 2) the ability to reduce the incidence of the zero lower bound. The two different criteria approximately capture the performance of each regime in both normal times and when monetary policy is constrained by the zero lower bound.

4.1 The model

For the evaluation of each strategy, I use a New Keynesian model in which households optimize utility (which generates the IS curve), firms maximize profits subject to nominal price rigidities (which originates the Phillips curve) and the central bank implements a targeting rule, i.e. minimises a loss function which accounts for the deviations from target of both inflation (or the price level) and the output gap, subject to the constraint provided by the Phillips curve. The endogenous persistence in the model suggests that both aggregate demand and aggregate supply depend not only on expectations about the future but also on lagged inflation and output gap.

The specification and calibration of the model follow Busetti *et al.* (2017) for the IS and Phillips curve. Each parameter is estimated on euro area data for the period 1995-2012.

$$\begin{gathered} \pi_t = \psi E_t \pi_{t+1} + (1-\psi)\pi_{t-1} + \kappa x_t + u_t \\ x_t = \chi E_t x_{t+1} + (1-\chi) x_{t-1} - \sigma(i_t - E_t \pi_{t+1} - r^n) \end{gathered} \tag{1}$$

The first equation is the Phillips curve, which characterises the behaviour of inflation π_t, while the second equation is the IS curve, which captures the demand side of the economy through the output gap x_t, with the latter responding to the policy rate i_t. According to the calibration, firms are mostly forward-looking in setting prices ($\psi = 0.72$), while consumers optimise their utility[1] mainly on the basis of their past decisions ($\chi = 0.09$). The Phillips curve is fairly flat as shown by the parameter κ which is equal to 0.05 and the cost-push shock u_t in the Phillips curve is an autoregressive process of order one, whose persistence parameter ρ is equal to 0.75. In the IS curve, the intertemporal elasticity of substitution σ is equal to 0.53, while the real natural rate of interest r^n is adjusted to recent estimates and is equal to 1% annualised, in accordance with Kiley (2015) and Del Negro (2017).

A desirable monetary policy strategy minimises the discounted sum of current and future losses for society due to economic volatility, where the loss in each period is measured by a weighted sum of squared deviation of inflation from target and of output from potential. The central bank is assumed to act under discretion and its behaviour is summarised by the following problem:

$$\min_{x_t} E_t (1-\beta) \sum_{i=0}^{\infty} \beta^i L_{t+i} \tag{2}$$

[1] In this simple DSGE model, output equals consumption.

where the specific form of L_t depends on which strategy is adopted: inflation targeting, price-level targeting or average-inflation targeting. The time-*t* loss function in the above three cases is given respectively by:

$$L_t^{IT} = \frac{1}{2}\{[(\pi_t - \pi^*)\}^2 + \lambda x_t^2] \tag{3}$$

$$L_t^{PLT} = \frac{1}{2}\{[(p_t - p^*)\}^2 + \tilde{\lambda} x_t^2] \tag{4}$$

$$L_t^{AIT} = \frac{1}{2}\left\{\left[\left(\bar{\pi}_{j,t} - \pi^*\right)\right\}^2 + \bar{\lambda} x_t^2\right] \tag{5}$$

where $\bar{\pi}_{j,t}$ is the j-period average inflation rate, defined as:

$$\bar{\pi}_{j,t} = \frac{1}{j}\sum_{s=0}^{j-1} \pi_{t-s} = \frac{1}{j}\left(p_t - p_{t-j}\right) \tag{6}$$

The weight on output stabilization λ is calibrated according to Giannoni (2010) and is equal to 0.048, which implies that the central bank is much more concerned with stabilizing inflation than the output gap.

The IT loss function is not only the criterion by which the central bank sets interest rates but it also coincides with a quadratic approximation of the representative household's utility function. Thus, the central bank's concern for price stability and economic activity is justified: absent inflation and output gap inertia, the difference between the expected loss given by (3) and the utility-based social welfare criterion is insignificant (the error is an infinitesimal of order three). It is then reasonable to compare the different strategies (in normal times) in terms of equation (3) and more specifically:

$$L_t^{Society} = Var(\pi_t) + \lambda Var(x_t) \tag{7}$$

which corresponds to the expected per-period utility of private agents.

The comparison between the alternative monetary strategies is done by means of stochastic simulations[2]: I generate 1000 replications for 200 periods (i.e. 50 years) and calculate for each policy framework the overall frequency (in percentage terms) of negative interest rates.

The mean and maximum duration of ZLB episodes (consecutive quarters where the interest rate is negative) in each framework is also considered. Additionally, for all strategies, I calculate the variability of the endogenous variables and the policy (or efficiency) frontier.

[2] Stochastic simulations are done with the software Dynare.

4.2 Results

The first criterion used to assess the effectiveness of these strategies is the volatility of the endogenous variables. A policy framework in which inflation, output gap and interest rates are highly unstable should not be adopted even if it could eliminate the threat of a liquidity trap. Unfortunately, the simple 3-equation New-Keynesian model fails to capture the increase in macroeconomic volatility caused by a higher target, as it does not allow to evaluate the costs of high trend inflation. Indeed, the loss function is the same for any IT strategy regardless of the value of the inflation objective. Thus, the variances of a 2% IT strategy are exactly the same as those obtained with a 4% target.

*Table 1: **Variances and expected loss under alternative policy frameworks***

	Commitment	Discretion				
	IT(2%)	**IT(2%)**	**PLT**	**IT(4%)**	**AIT(8 p.)**	**AIT(12 p.)**
Var(π)	0.0248	0.1428	0.0089	0.1428	0.1783	0.1994
Var(x)	0.9035	0.5658	1.4818	0.5658	0.2408	0.1555
Var(i)	0.3442	0.8047	1.0311	0.8047	0.3748	0.3177
Loss	0.0682	0.1699	0.0801	0.1699	0.1127	0.0895

Between all strategies, PLT achieves the lowest inflation variance in the model but at the expense of increased volatility in the output gap and interest rate. The existence of a volatility trade-off between inflation and the output gap should not come as a surprise. As shown above, even through policy commitment the central bank is not able to improve the variance of inflation without worsening output gap volatility. In this respect, PLT seems to be even more efficient than commitment in keeping low the variance of inflation (0.0089 against 0.0248), although commitment almost halves output gap variability. The difference between PLT and IT under discretion is striking: IT increases inflation variability by a factor of 16 while decreasing output gap variability by more than one half. Though such differences may be partly due to the relatively short length of the simulations and to the limited number of replications, they clearly point to the greater effectiveness of PLT. Finally, the two different types of average inflation targeting perform poorly in terms of inflation variance but are the most effective in stabilising the output gap.

The efficiency of each strategy in achieving policy objectives is measured by the loss function in equation (7), which represents society's preferences. Save IT under commitment, which outperforms all other targeting rules under discretion and is used as benchmark, model simulations generate the following ranking - from best to worst - among strategies: 1) PLT, 2) AIT (average taken over 3 years), 3) AIT (average taken over 2 years), and 4) IT (under discretion), regardless of whether the inflation target is 2% or 4%. Although model simulations generate an apparent tie between IT strategies with different inflation objectives, it should be stressed that a higher inflation target is expected to produce more instability and costs that are not measured by the loss function and thus IT with a higher π^* might perform worse than all the other frameworks. Notice also that the outcome is sensitive to the weight given to output gap stabilisation, which is low in the baseline case ($\lambda = 0.048$), and the ranking may be quite different for different values of λ. Also, interest rate variability is not accounted for in (7), since supposedly society is only concerned with stable inflation and output gap.

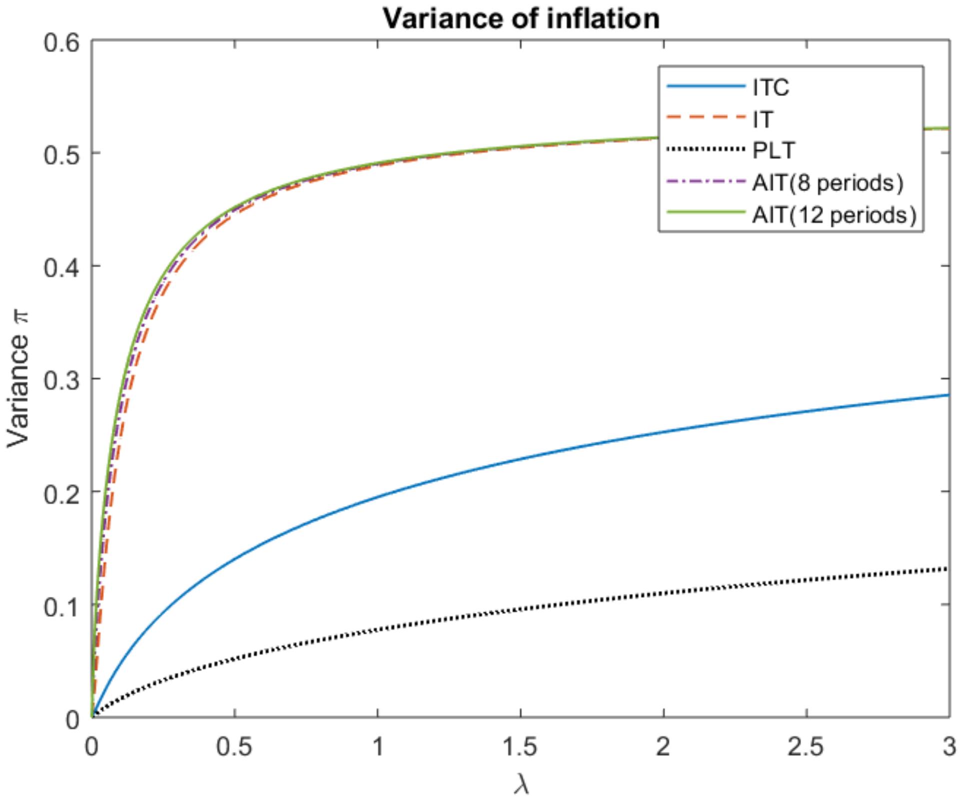

Figure 1: ***Variance of inflation under alternative policy frameworks***

The findings on the inflation-output gap trade-off seem to be robust to different values of λ, i.e. the weight on output stabilisation. Figures 1 and 2 show that under discretion, PLT has the best performance in stabilising inflation (and the worst in reducing fluctuations of the output gap) while the two AIT strategies are successful in minimizing the volatility of the output gap. The performance of IT under discretion does not differ much from that of AIT, regardless of whether we consider 8-or 12-quarter inflation averages. Notice that PLT and the two AIT strategies have an advantage over the current inflation targeting framework: the government can delegate to the central bank the minimisation of a loss function that does not match society's if this enhances social welfare. Thus, PLT can achieve a lower output gap variance with respect to IT by changing the weight on output stabilisation in (4) and AIT as well can achieve a lower inflation variability by doing the same. It could be possible then that price-level targeting simultaneously achieves a lower variance in inflation and output gap simply by modifying λ, as in Vestin (2000). A plot of the efficiency frontier for each strategy shows that such an outcome is indeed possible.

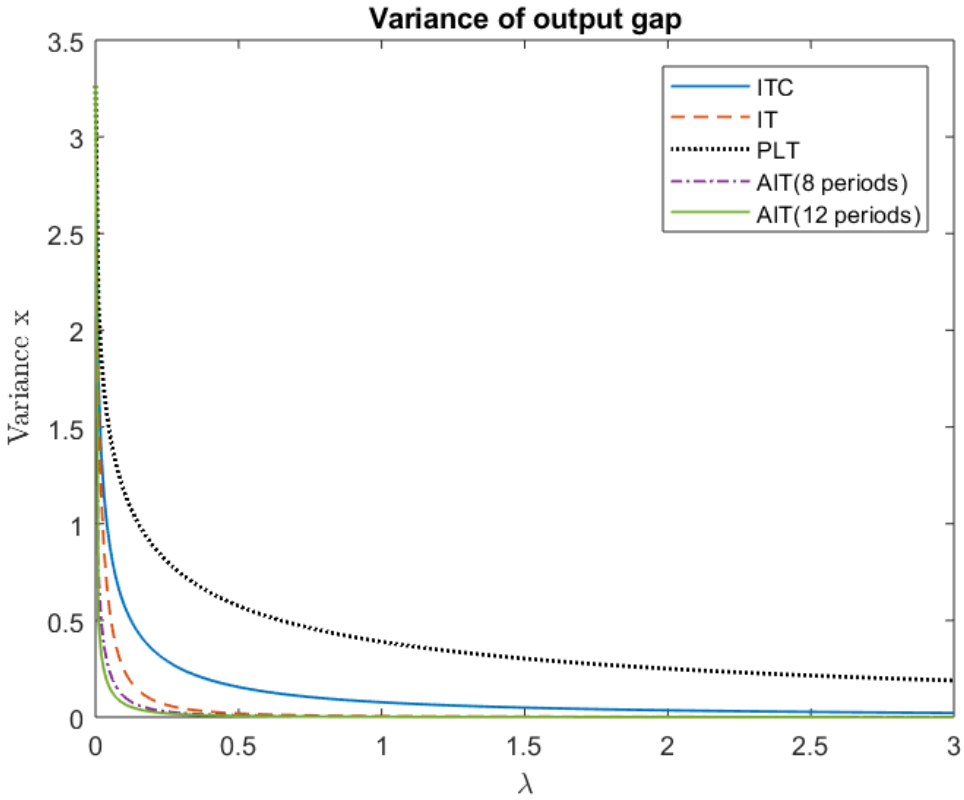

Figure 2: ***Variance of output gap under alternative policy frameworks***

The policy frontiers are built by plotting all the possible combinations of the inflation and output gap variance for different values of λ. To do this, all parameters in the model remain fixed with the exception of the weight on output stabilisation. It can be easily seen from Figure 3 that the PLT policy frontier crosses the IT once, at the very beginning, when λ is close to zero, and then delivers a superior trade-off of inflation-output gap variability that improves when λ rises. For this reason, it is not possible to conclude that PLT strictly dominates IT, but it is a better alternative when the central bank acts under discretion. When the central bank is able to commit, PLT comes very close to replicating the commitment solution (varying λ accordingly), which can be seen from the figure, where the policy frontier for PLT and IT under commitment almost coincide. This result is due to the fact that price-level targeting makes up for past errors in hitting the inflation target and, in so doing, it mimics the history dependence feature of policy commitment.

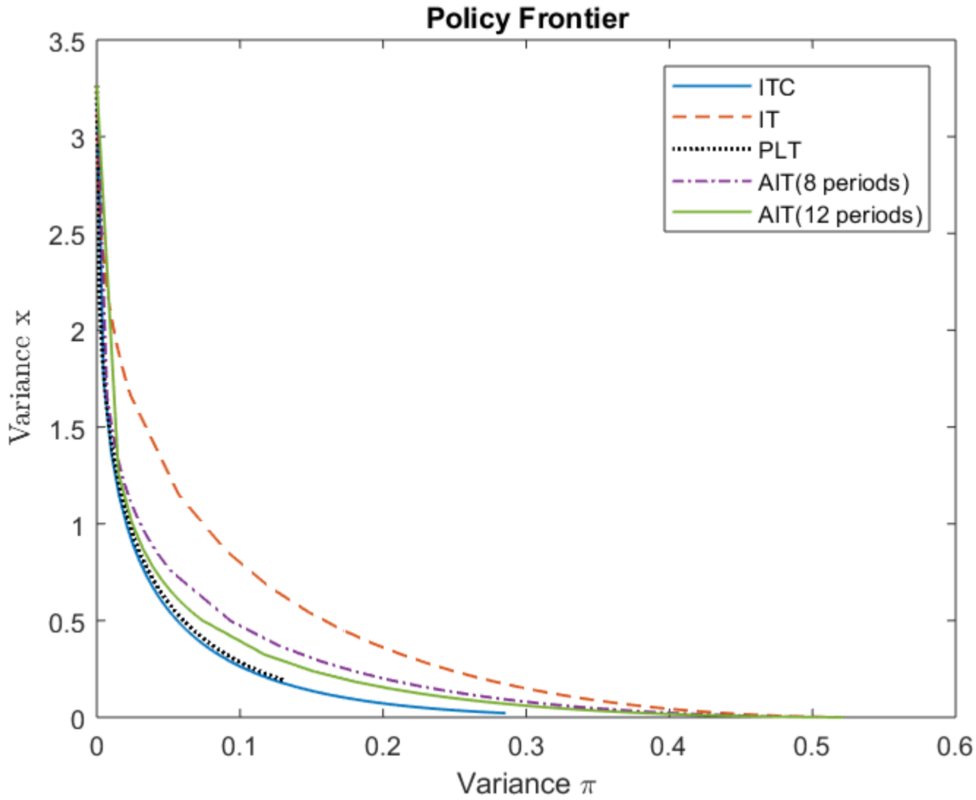

Figure 3: ***Policy frontier under alternative policy frameworks***

The second criterion used to measure the success of each strategy is its ability to reduce the chances of incurring a liquidity trap. The recent literature suggests that with the fall of the natural rate of interest, it has become far more likely that the ZLB may be hit in the future. So, the first step is to calculate the probability of hitting the zero lower bound. With a natural rate of interest of around 1%, the likelihood of a binding ZLB is strikingly high: under all the regimes analysed, it is guaranteed that the ZLB will be binding with non-zero probability. Thus, the simulations seem to highlight the urgency of finding a solution to this problem. Secondly, the frequency and severity of ZLB episodes will be quantified for each strategy. These two indicators give an insight into the severity of the issue: ideally, it would be best to have a strategy which keeps in check both the frequency and severity of ZLB episodes. However, it can be complex to determine whether one strategy outperforms another if the two indicators do not go in the same direction. Clearly, if the economy is stuck for a long time in a liquidity trap, the strategy is not very effective, even if the frequency of hitting the ZLB is low. On the other hand, a regime in which the ZLB is often binding is not successful in stabilising the economy.
The frequency of the ZLB incidence is calculated by counting, for each replication, the number of periods in which the nominal interest rate is negative out of the 200 quarters included in each simulation and by taking an average of all replications. The severity of each episode will be determined by computing the average and maximum length of consecutive periods characterised by a negative nominal interest rate[3].

[3] Simulations are made without imposing the ZLB, therefore the probability and length of ZLB episodes is understated. The ranking of policies hopefully is not affected.

*Table 2: **Performance at the ZLB of alternative monetary policy frameworks***

	Commitment	Discretion				
ZLB	**IT(2%)**	**IT(2%)**	**PLT**	**IT(4%)**	**AIT(8p.)**	**AIT(12p.)**
Frequency (%)	10.04	20.08	22.93	8.16	10.97	9.11
Mean length	1.7	1.4	2.1	1.2	1.5	1.5
Max length	8	10	8	6	9	11

From my analysis, the most effective strategy for keeping at bay the probability of falling into a liquidity trap is inflation targeting with a 4% target. IT with a 4% target is associated with an 8.16% probability of the ZLB binding. The low incidence is not surprising since raising the inflation target gives the central bank much more room for lowering the nominal interest rate in case of a negative cost-push shock. However, it is a little unexpected that it outperforms all other strategies, particularly those characterized by some degree of history dependence. Moreover, the maximum and average length are 6 and 1.2 quarters respectively, the lowest values in the sample. Other strategies, like commitment and both types of average inflation targeting, come close to the effectiveness achieved by raising the inflation objective: the incidence remains below 11%, the average length is around 1.5 quarters and the maximum length is in the range of 8-11 quarters.

It should be stressed out, however, that simulation results probably overestimate the ability of a higher inflation target to reduce the incidence of the ZLB. As shown by Ascari and Ropele (2009), a higher π^* causes the Phillips curve to flatten, requiring *ceteris paribus* wider movements in the policy rate to stabilise inflation, which increases the probability of hitting the ZLB. The model used in the simulations does not link the parameter κ in equation (1) to π^* and accordingly, biases simulation results in favour of strategies that raise the inflation target[4].

Much less successful are IT with π^*at 2% and PLT, which achieve the worst performance in the model. In the case of the former, this result is probably given by the inability to exploit the anchoring of inflation expectations in the absence of commitment, causing inflation volatility to rise. This increase, in turn, leads interest rates to move more in order to tame inflationary (or disinflationary) pressures. Also, in the case of PLT, the poor performance at the ZLB can be attributed to high-interest rates volatility, but for different reasons. As seen before, PLT raises output gap variability more than any other strategy and this has an impact through the IS curve on the variance of the interest rate. But why is the output gap so volatile? In Section 2, it was emphasized that PLT is very effective when expectations are forward-looking. In the model, agents' expectations are mostly forward-looking when it comes to setting prices but are almost entirely backward-looking when it comes to consumption. As a matter of fact, the weight on forward-looking expectations in the IS curve is 0.09, which implies that consumers make their spending choices mostly on the basis of their decisions in the previous period. Hence, the backward-looking behaviour of consumers could explain why volatility in the output gap, and therefore in the interest rate, is so high. Indeed, as it will be shown in

[4] Budianto (2018) objects to the commonly held view that a higher inflation target reduces the incidence of the ZLB and shows that the opposite may happen. Using a standard New Keynesian model, she shows that a higher inflation target changes the price-setting behaviour of firms, forcing them to become more forward-looking and making inflation more volatile. The resulting higher volatility of the nominal interest rate implies that the economy ends up more often rather than less often at the ZLB.

the next section, for lower degrees of inertia in the IS curve, PLT is much more effective in reducing the probability of hitting the ZLB.

4.3 Limitations

A limitation of the quantitative analysis presented in this thesis is that all findings are based on the assumption that economic agents adjust immediately to the new policy framework, behaving as if it had been in place for a long period of time with no implications for central bank's credibility, so that the monetary authority in all circumstances remains fully effective in anchoring expectations. Additional research is needed to address in a more comprehensive and reliable way how to design and implement the transition to the "New Normal" of monetary policy.

5. Sensitivity analysis

In this section, I assess the sensitivity of the results *ceteris paribus*, to some of the more relevant parameters of the model, namely: i) the degree of inertia in both the Phillips curve (ψ) and the IS curve (χ); ii) the slope of the Phillips curve (κ); iii) the persistence of the cost-push shock (ρ); iv) the intertemporal elasticity of substitution (σ) in the IS curve; iv) the natural rate of interest (r^n).

In the first case, I expect the performance of price-level targeting to improve as the degree of forward-lookingness increases. In the second, I expect the inflation and output gap variance trade-off to worsen with a flatter Phillips curve, but without relevant changes in the ranking of the targeting rules. In the third case, I predict a lower interest rate variability and thus a lower ZLB incidence, while with a more persistence cost-push shock I foresee a worsening performance across all regimes both in normal times and at the ZLB. Finally, I expect a much higher probability of hitting the ZLB for lower values of the natural rate of interest.

Degree of inertia. For a lower degree of inertia in the Phillips curve, both the expected loss and the ZLB incidence of PLT decrease. In the case of a purely backward-looking Phillips curve, PLT[6] delivers the worst performance on both counts. Interestingly enough, in the latter case, the performance of PLT lags behind the two alternative specifications of average inflation targeting even in normal times. This implies that while for PLT the expected loss is a monotonically increasing function of the degree of inertia, for average inflation targeting this is not the case. For example, the expected loss for AIT strategies increases for values of ψ between 0 and 0.55 and then drops significantly for values higher than 0.55.

It seems that in a model with endogenous persistence in the IS curve, a purely forward-looking Phillips curve is not enough for PLT to outperform AIT even in normal times, as opposed to Néssen and Vestin (2005).

On the other hand, for a lower degree of inertia in the IS curve, we have a much-improved performance of all regimes at the ZLB, and in particular of PLT[7]. For sufficiently low values of inertia

[6] The focus is on PLT performance because there is a broad body of literature highlighting its effectiveness when agents in the economy are forward-looking.}

[7] Since in the baseline case, interest variability is not included, PLT performance in normal times, measured by (4), is the same as in the baseline, ranking second in place after commitment.

($\chi \geq 0.70$), ZLB incidence under price-level targeting is even lower than an inflation targeting with a 4% inflation objective.

Slope of the Phillips curve. A flat Phillips curve seems to imply that the effectiveness of all the strategies analysed suffers and so does the inflation and output gap variance trade-off. For lower values of the slope of the Phillips curve, both the expected loss and the ZLB incidence increase for all targeting rules. The ranking of the strategies remains unaltered with respect to the baseline case.

Persistence of the cost-push shock. As expected, if a cost-push shock has longer-lasting effects, all strategies are less successful in stabilising the economy and preventing a ZLB episode. However, in normal times the strategy that comes closer to the optimal commitment solution is price-level targeting and this result holds for every value of ρ.

The ranking in normal times is unaffected by the value of ρ, while the ranking at the ZLB is different on the basis of the degree of shock persistence: for low values of ρ, the two AIT strategies outperform inflation targeting with a 4% objective, while for $\rho \geq 0.95$ PLT is the most effective regime at the ZLB, second only to commitment.

Intertemporal elasticity of substitution. Letting the intertemporal elasticity of substitution (σ) vary, does not affect the performance of any of the strategies in normal times and therefore the ranking given by the expected loss function remains unchanged from the baseline. This is, however, a misleading finding, because the optimisation procedure uses the output gap as the policy instrument, under the presumption that the policy rate can always ensure that the output gap is at the desired level. Unfortunately, the lower σ, the larger the movements in the policy rate that are needed to control the output gap. As a consequence, interest rate variability is inversely related to σ and thus the performance at the ZLB worsen for lower values of the intertemporal elasticity of substitution regardless of the strategy considered. The ranking more or less stays the same.

Natural rate of interest. Changing the level of the natural rate of interest has an impact only on the incidence of the ZLB: as r^n increases, the likelihood of hitting the zero lower bound decreases. For instance, doubling the neutral rate of interest roughly halves the ZLB incidence with respect to the baseline case for all policy frameworks. The ranking remains unaltered.

In the baseline case, the two strategies lagging furthest behind the first-best, i.e. IT with a 4% inflation target, are the current IT framework and PLT. To reach roughly the same incidence as a 4% IT regime, the natural rate of interest should be around 3% for inflation targeting and around 4% for price-level targeting.

6. Interest rate in the loss function

An interesting experiment is to modify the loss function in order to include deviations of the interest rate from its steady-state value. This is generally done under the assumption that both the public and the central bank care about variations in the interest rate, either to avoid disruption in financial markets or to account for the ZLB.

The Great Recession showed that stabilising inflation and the output gap does not necessarily imply financial stability, and financial instability can lead to severe economic downturns. Furthermore, high volatility in the interest rates increases the likelihood of ZLB episodes. Thus, minimising interest rate variability, along with inflation and the output gap, could be beneficial.

In this case, society's welfare function is described as:

$$L_t^{Society} = \frac{1}{2}\{[(\pi_t - \pi^*)\}^2 + \lambda_x x_t^2 + \lambda_i (i_t - i^*)^2] \quad (8)$$

where i^* is the steady-state value of the interest rate and is defined as $i^* = r^n + \pi^*$. The loss functions delegated to the central banks are the same as equations (3)-(5), with the addition of the last term in (8). The weight on output stabilisation is the same as in the baseline case, while the weight on interest rate stabilisation is calibrated according to Woodford (2003) and Giannoni (2010).
With respect to the baseline case, the expected loss across all the regimes increases while the frequency of the ZLB halves for all frameworks, with the exception of the 4% inflation targeting framework whose performance worsens slightly. Neither finding is particularly surprising: society's loss now incorporates a new variable that the central bank needs to stabilise, so it is bound to be higher than in the baseline scenario, while reducing the deviations of the interest rate from its target - and thus interest rate variability - should contain the probability of a binding zero lower bound.

*Table 3: **Interest rate in the loss function: results***

	Commitment			Discretion		
	IT(2%)	**IT(2%)**	**PLT**	**IT(4%)**	**AIT(8 p.)**	**AIT(12 p.)**
Loss	0.0822	0.2302	0.1476	0.2302	0.1467	0.1200
Var(π)	0.2500	0.1407	0.0194	0.1407	0.1682	0.1963
Var(x)	0.0000	0.2955	1.0818	0.2955	0.1709	0.1119
Var(i)	0.1504	0.3193	0.3230	0.3193	0.2277	0.1997
Frequency (%)	2.67	9.17	9.31	1.37	5.81	4.68
Mean length	1.8	1.6	3.0	1.3	1.8	1.8
Max length	7	10	8	6	11	11

One noteworthy finding is that if we account for interest rate variability in the loss function, the ranking of the different strategies changes with respect to the baseline case in normal times, while it is mostly left unchanged at the ZLB. IT under commitment remains, of course, the optimal policy, but the two- and three-year AIT work their way up the ranks. In fourth place, there is price-level targeting, followed by the two IT frameworks (under discretion). According to both evaluation criteria, IT (with a 2% target) performs poorly and is not particularly effective either in normal times or at the ZLB. When interest rate variability matters, PLT is no longer in the top position in the ranking and falls in fourth place, without managing to improve its performance at the ZLB either.
A higher inflation target is the most effective strategy at the ZLB, but displays the biggest expected loss, even without accounting for the costs associated with the higher inflation objective. Hence, the performance of these strategies is lacking in some respects (or in all respects, as in the case of a 2% inflation targeting regime).
Excluding commitment, a 3-year average inflation targeting seems to be the most reliable policy framework, with a 0.12 expected loss and a ZLB incidence of 4.68%. Furthermore, the average duration of the ZLB episodes is under two quarters. The two-year AIT, while obtaining outcomes very close to its longer counterpart, performs slightly worse.

7. Conclusions

Using a simple three-equation New Keynesian model, estimated on euro-area data and assuming a natural rate of at most 1%, the probability of reaching the zero lower bound in the current setting is 20.8%. The main finding of my research is that alternative monetary policy frameworks can warrant more benign outcomes.

With endogenous persistence in the model, in normal times PLT is superior to any other strategy analysed, but its performance at the ZLB is sub-optimal. From the results of the sensitivity analysis, it is clear that the relative performance of PLT in normal times depends on the degree of inertia in the Phillips curve, while when at the ZLB it depends on the weight of lagged output gap in the IS curve. On the other hand, average inflation targeting seems to be effective both in normal times and when monetary policy is constrained by the ZLB. Its effectiveness also appears to be robust to different specification of the model. Differently from Nessén and Vestin (2005), I find that for any degree of inertia in the Phillips curve (even for a very backward-looking economy), average inflation targeting dominates the current IT framework, the more so the longer the horizon over which average inflation is computed.

Further research on average inflation targeting is also recommended, since it seems to be second-best, both in normal times and at the ZLB, with a loss in efficiency from the first-best outcome of only 10% in both cases. Additionally, such a strategy does not require a switch in regime, which implies less learning costs, and it does not bring about the potentially very significant costs of targeting a higher inflation rate. Finally, it is the only alternative among those analysed which has been actually adopted by at least a central bank of a developed country, i.e. the Bank of Australia.

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