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HOW TO COPE WITH THE EFFECTIVE LOWER BOUND AND A LOW NEUTRAL RATE: A COMPARISON OF ALTERNATIVE MONETARY POLICY STRATEGIES

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Declaration

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Contents

Abstract

This dissertation studies whether inflation targeting is an idea past its sell-by date. Inflation targeting has been the monetary policy strategy adopted by the central banks of most developed economies in the last quarter of a century, but developments in recent years have cast doubts on the possibility that it will maintain its prominence in the future. The global and the sovereign debt crises on the one hand and the steady decline of the natural rate of interest on the other hand, have shown that the probability of hitting the effective lower bound (ELB) is much higher than previously thought. In the last decade, output and inflation have remained below their desired values for a long period of time, notwithstanding the efforts of central banks to provide as much stimulus as possible. A low level of the natural rate of interest increases the probability of hitting the ELB and reduces the room for manoeuvre of policies mostly based on interest rate management: a skilful steering of expectations becomes essential to restore the effectiveness of central banks' actions and in this respect inflation targeting seems lacking. There is by now a vast literature showing that inflation targeting underperforms other monetary policy strategies in steering expectations because it does not exhibit history dependence. The objective of this dissertation 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 frameworks seem able to outperform even the strategy suggested by Krugman (2009) and Blanchard *et al.* (2010), i.e. inflation targeting with a higher inflation objective. Robustness checks are made in order to assess whether the ranking of monetary policy strategies is sensitive to changes in model parameters or in the shock persistence.

Introduction

The topic discussed in this thesis is whether inflation targeting is an idea past its sell-by date. The research question I attempt to answer is what alternative monetary policy 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 effective lower bound (ELB) of monetary policy interest rates.

In chapter 1, I describe the main challenges for monetary policy. The global financial crisis (GFC) and the sovereign debt crisis have led central bankers to rethink how monetary policy should be conducted and implemented. In particular, the design of a "New Normal" needs to take into account not only the lessons learnt from the twin crises but also the steady decline in the natural rate of interest and the worsening of the output-inflation trade-off. With the outbreak of GFC, the inflation targeting regime has come into criticism, in particular, its ability to fight deep recessions.

The third chapter presents a review of the economic literature on the alternative monetary policy strategies proposed in order to cope with the effective lower bound, which reduces the room for manoeuvre for standard monetary policies. There seem to be two different schools of thought on the matter: evolution or revolution. The first one argues for changes in the present monetary policy framework, suggesting in particular 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 for an inflation targeting regime.

In the fourth and conclusive chapter, 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, while 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) the variability of inflation, the output gap and, in some cases, the monetary policy interest rate, and 2) the ability to reduce the incidence of the zero lower bound.

I provide empirical evidence that history-dependent strategies like price-level targeting or average inflation targeting are more effective in stabilising the economy and/or in reducing the frequency of ELB episodes with respect to the current inflation targeting regime. These alternative monetary policy frameworks seem able to outperform inflation targeting even when a higher inflation objective is considered.

Chapter 1

Challenges for monetary policy

1.1 The decline in the natural rate of interest interest

The global financial crisis and the sovereign debt crisis have led central bankers to rethink how monetary policy should be conducted and implemented. In particular, the design of a ”New Normal” needs to take into account not only the lessons learnt from the twin crises but also the steady decline in the natural rate of interest and the worsening of the output-inflation trade-off.[1]

The natural rate of interest, whose concept was introduced for the first time by Knut Wicksell in 1898[2], can be defined as ”the real short-term interest rate consistent with output equaling its natural rate and constant inflation”.[3] For Wicksell (1898) ”There is a certain rate of interest on loans which is neutral in respect to commodity prices, and tends neither to raise or lower them. This is necessarily the same as the rate which would be determined by supply and demand if no use were made of money.” The natural rate of interest, also called the long-term equilibrium real interest rate or the neutral real rate, is the real interest rate that would keep the economy at full employment (of labour and capital resources) and stable inflation close to the monetary

[1] Brainard (2017), Rethinking Monetary Policy in a New Normal, intervention at the Panel on Monetary Policy ”Rethinking Macroeconomic Policy” held at the Peterson Institute for International Economics.

[2] Wicksell K., (1898):”The Influence of the Rate of Interest on Commodity Prices”, reprinted in Lindahl, E. ed., (1958): Selected Papers on Economic Theory by Knut Wicksell.

[3] See Holston *et al.* (2016).

authority's target.[4]

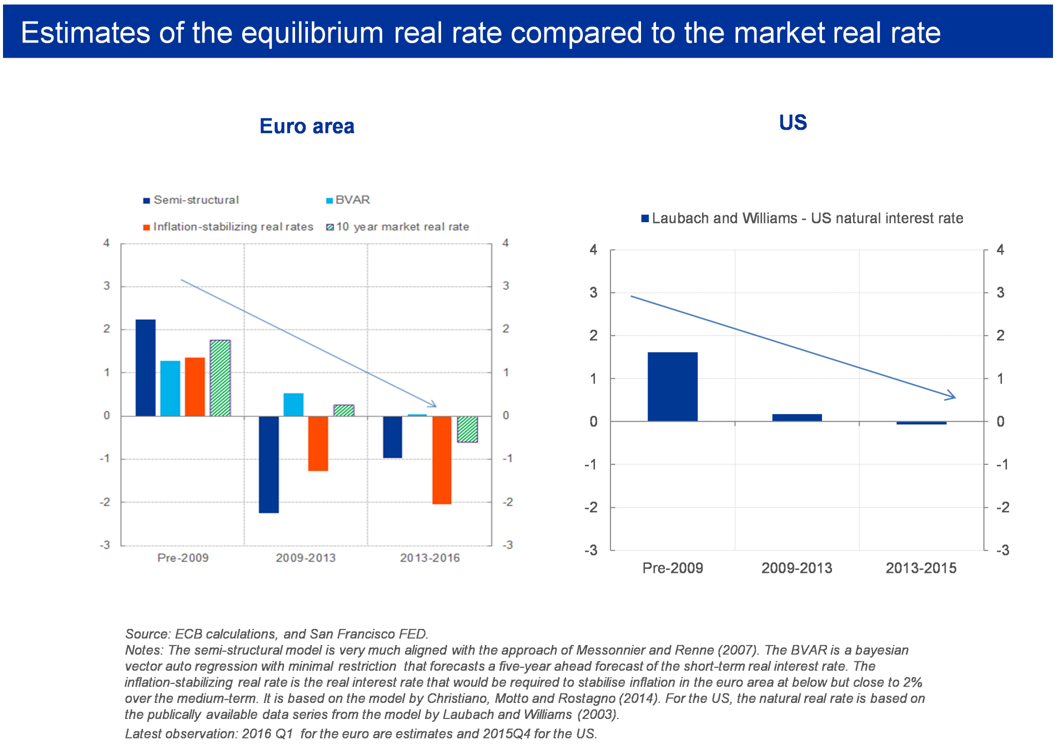

Fig. 1.1: *Estimates of the equilibrium real rate compared to the market real rate*

The natural rate of interest has declined over the past 25 years, reaching historically low levels since the start of the global financial crisis (GFC). This fall has interested all the major advanced economies over the last decades. Even if the measurement of the natural interest rate is very challenging (it must be inferred because it is not directly observable), the sizable decline in the natural interest rate in many advanced economies was proved by a lot of researches, even using different methodologies. According to the updated estimates of the baseline model described in their 2003 paper, Laubach and Williams (2016) assess that the US natural rate of interest, which was about 2% before the crisis, has become slightly negative in 2017. Holston, Laubach and Williams estimated the natural interest rates not only for the United States but also for Canada, the Euro Area and the United Kingdom, showing that in all countries they have

[4] Bernanke (2015). "Why are interest rates so low?" Monday, March 30, 2015.

experienced a ”moderate secular decline” in the period 1990-2007 and a stronger reduction over the last decade. Constâncio (2016) find a sharp drop in the natural interest rate during the GFC in the Euro Area and in the United States (see Figure 1.1), using three different methodologies for estimates (1. a time series approach - BVAR; 2. a semi-structured approach such as the Laubach and Williams method, 2003; 3. an alternative approach that calculates the real interest rate that, if maintained for some time, would stabilise inflation). These findings also give evidence of the high degree of uncertainty that affects the measurement of the equilibrium real rate.

To better emphasize the uncertainty in estimates and projections, the confidence intervals for mid-point estimates of the euro area are shown for different studies and methods implemented (see Figure 1.2). The uncertainty of the estimation is given by the grey-shaded area whose width represents the degree of uncertainty. The studies in Figure 1.2(a)-1.2(d) implement econometric approaches, while the other two make use of business-cycle models. The econometric approaches display a significant margin of error mainly due to the high persistence of the shocks affecting the natural rate but present a much smoother estimate since they strip down frequency caused by cyclical factors. Furthermore, they display the highest degree of uncertainty in the projections for the future. Estimates from DSGE models are noisier and appear to be much more accurate in their predictions for the future, but this is only because the autoregressive structure of the exogenous shocks causes mean-reversion to the steady-state value.

Finally, other studies confirm the steady decline of the natural (or neutral) interest rate for Canada (Mendes employed several different approaches to estimate the neutral rate, identifying the real neutral rate in a range from 1 to 2%) and Japan (Fujiwara *et al.* 2016). Recent researches using dynamic stochastic general equilibrium (DSGE) models also reach the same conclusions (Curdia 2015, Goldby *et al.* 2015).

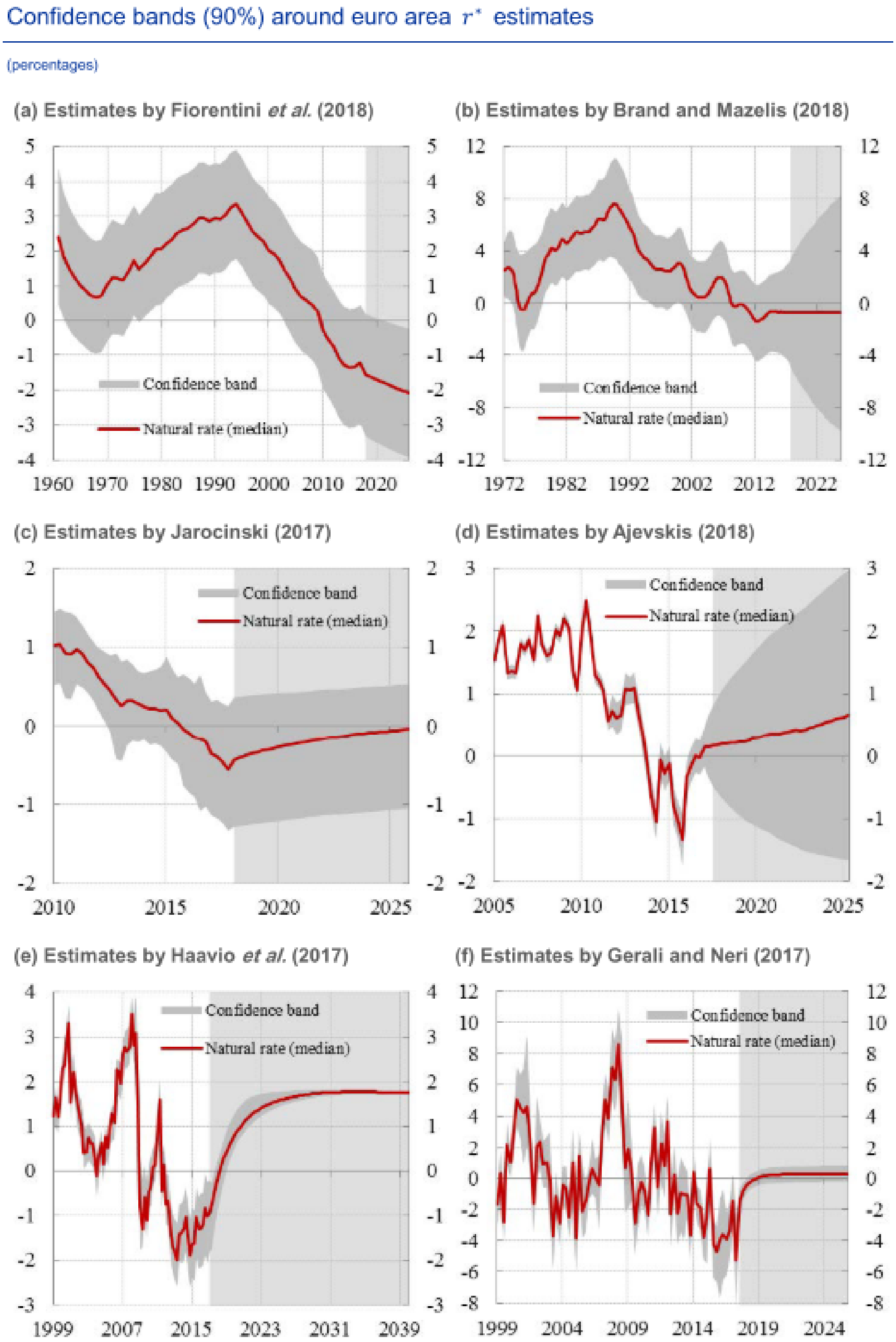

Fig. 1.2: *Uncertainty around estimates of r* (Brand et al., 2018)*

1.2 Drivers of the fall of the natural rate of interest

Many factors affect the natural interest rate and many of them are global rather than country-specific (Laubach and Williams 2016). I focus mostly on the first kind of drivers and among the most cited ones, are the following:

1. demographic developments such as lower fertility rates, longer life-expectancy and increase in the dependency ratio (generally captured in OLG-based approaches);
2. income inequality which affects preference in savings and could possibly lead to lower human capital accumulation;
3. the global saving glut, i.e. an excess of savings in particular by 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.

Demographic developments. Carvalho *et al.* (2016) identify three different channels through which demographics affects the natural rate of interest. The first one is through higher life expectancy while the other two channels are through fertility rates but with opposite signs. In most advanced countries, lifespan has increased by ten years between 1960 and 2010 while population growth is declining after having reached its peak around the 60s-80s. An increase in life expectancy lengthens the retirement period, which in turn shifts the preference in savings inducing workers to save more in anticipation. This increase in savings puts downward pressure to the real nominal rates.

Another source of downward pressure on equilibrium rates is a decrease in fertility rates, since it translates into lower labour supply and higher capital-labour ratio, which in turn bring down the marginal product of capital and hence real rates. Lower population growth however has also a positive effect on natural rates through the dependency ratio, i.e. the fraction of retirees to workers. As described by Modigliani's life-cycle theory of savings, retirees tend to spend more, driving up aggregate consumption and lifting up also real rates. Carvalho and his co-authors found that 1.5% of the decline in equilibrium real rates was explained by these demographic transitions and in particular by the rise in life expectancy.

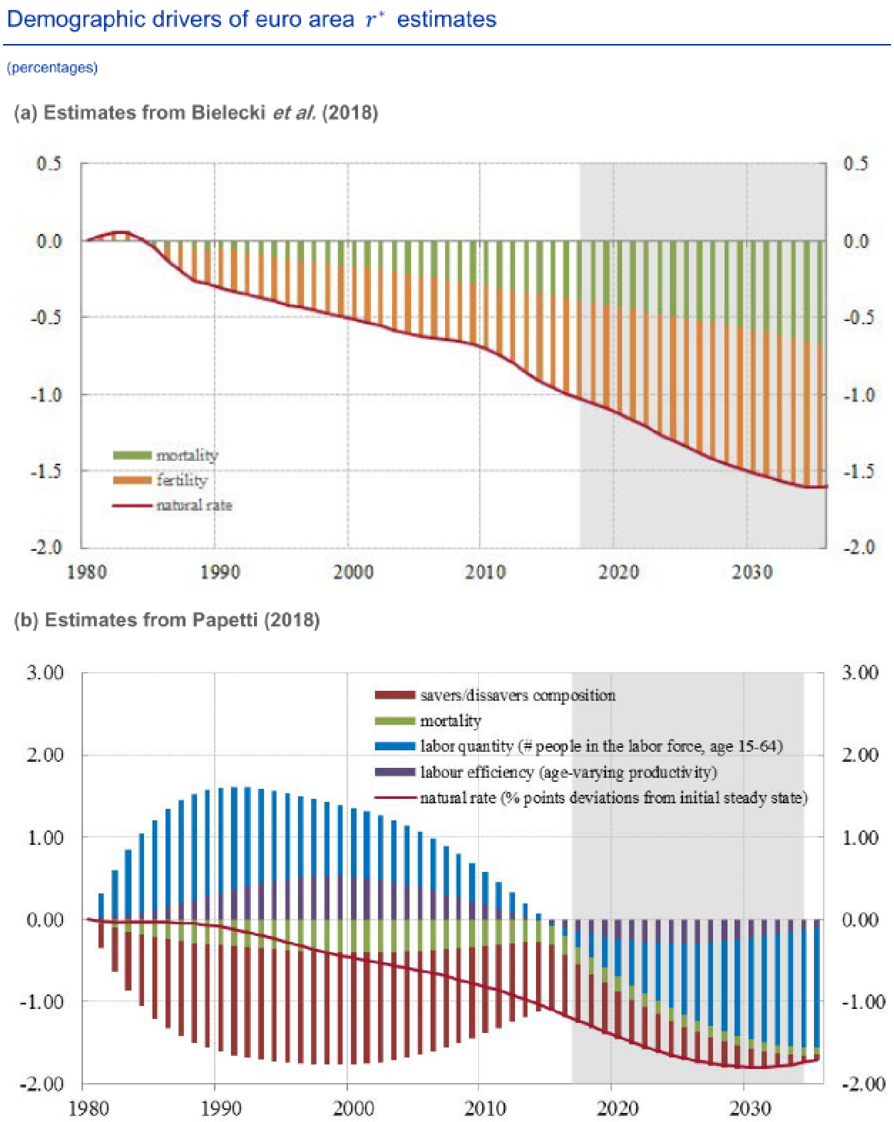

Fig. 1.3: *Demographic drivers of r^n (Brand et al., 2018)*

Other studies agree on the importance of demographics as a driver of the decline in the natural rate but disagree on the magnitude of each channel. Bielecki *et al.* (2018) similarly explained one percentage point of the decline in r^n with changes in fertility and mortality equally accounting for this change. Papetti (2018) quantifies the effect of ageing in the fall of r^n with an estimate of around 0.8 percentage points (pp). This study relative to the previous one better distinguish the three channels, assigning more importance to the second (lower labour supply) in driving down the natural rate of interest. However, both studies agree in predicting an even lower natural rate by 2030 (by 0.5 additional percentage points), since demographics are largely predetermined (see Figure 1.3). These findings are a source of concern, not only in relation to r^n but also in relation to economic growth. Lower labour participation, in particular, could drag down also potential output growth.

Income inequality. Inequality is also driving down the neutral rate of interest. Rachel and Smith (2015) identify two different channels through which income inequality have an impact on r^n: through economic growth and savings preference. The impact of inequality on growth tends to be ambiguous, but lately, both the IMF and the OECD concluded that its impact is negative. Rachel and Smith describe three ways in which inequality could hinder growth: i) by reducing incentives for business to invest as a consequence of higher corporate taxation; ii) by reducing human capital accumulation as education becomes less affordable to lower-income households, and iii) by reducing incentives for innovation if the latter depends on domestic demand. In accordance with the IMF/OECD estimates, they found that rising income inequality could have curtailed US growth by up to 0.6 pp per year[5]. The decrease in growth translate in downward pressure on the natural rate (as will be explained in the next point).

The second channel through which inequality affects r^n is a shift in savings preference. It

[5]The authors recognize that the effect of income inequality on growth for the US has probably been overestimated.

has been proved that rich households are likely to have a higher propensity to save (Dynan *et al.* 2004). The richest fifth of the population saves an extra third of their income with respect to the rest of households, increasing savings by 3pp. The net effect on savings, after accounting for shifts caused by lower-income households, is estimated to be around 2pp (Piketty 2014, Cynamon and Fazzari 2014). Rachel and Smith conclude that this shift in savings accounts for 45 basis point (bps) of the decline in the natural rate of interest.

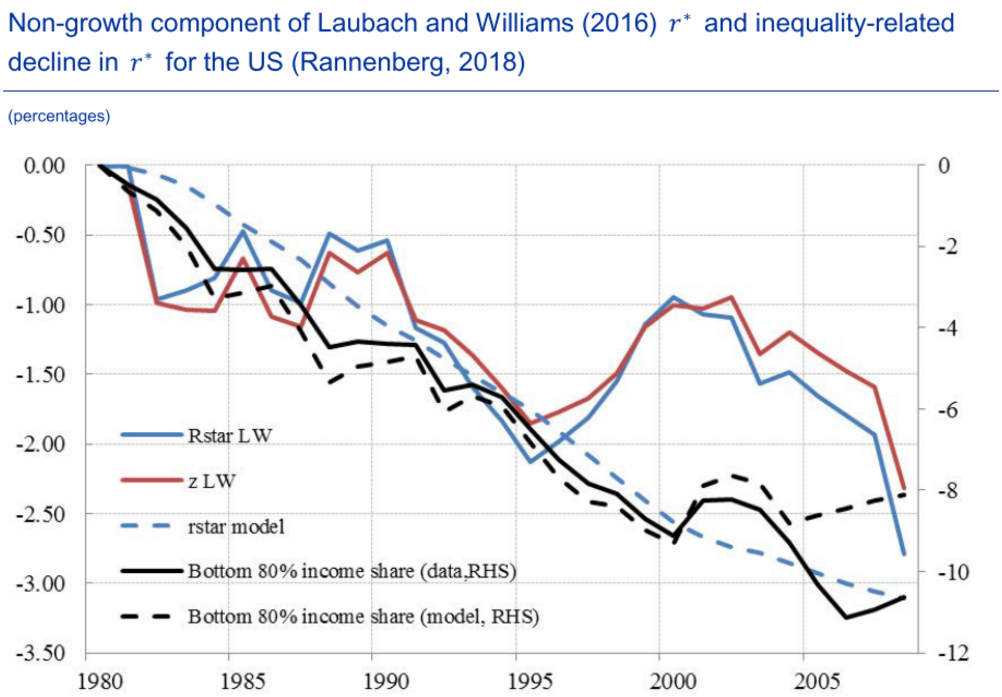

Fig. 1.4: *Inequality driver of r^n (Brand et al., 2018)*

More recently, Rannenberg (2018) found striking similarities between the evolution of income inequality and the non-growth component of Laubach and Williams (2016)[6]. Again, the increase in income inequality affects the neutral rate of interest through higher savings. In his model, the simulated fall in 80% income share occurred between 1980 and 2004 contributes to

[6] Laubach and Williams, in their model, decompose the natural rate of interest into a growth factor and a non-growth factor. The first term is the sum of consumption growth and population growth, while the second one is a "catch-all" factor.

the decline of r^n by more than 3pp (see Figure 1.4).

Savings glut. The savings glut hypothesis was first introduced by Bernanke in 2005. In his speech at the Sandridge Lecture, he linked the increased US current account deficit (around 5.5% of GDP in 2004) to the excess savings occurring in emerging market economies (EMEs), which put downward pressure on the natural rate of interest. At the time, US savings were quite low and not sufficient to cover domestic capital investment. Therefore, the investments were funded by foreigners' savings and, in particular, by emerging economies. By comparing the current account of a vast number of countries, he realized that the increase in the US current account deficit was largely offset by an increase in EMEs current account surpluses (a net change in surplus of $293 billion between 1996 and 2003). In fact, following the crisis in Mexico (1994), in East Asian countries (1997/1998), in Brazil (1999) and in Argentina (2000), most developing countries started to accumulate foreign-exchange reserves, as a precaution against the occurrence of a sudden stop of capital flows and against a possible currency appreciation. The current account surplus of oil exporters (the Middle East and Africa) also increased, reflecting the boost in oil revenues due to high prices. Thus, the US current account deficit increased as a result of both higher global savings and the greater appeal to foreigners in investing in the US. In response to the excess in desired savings, the global neutral rate of interest has declined to equilibrate the market for global savings.

As of 2013, the US current account deficit has halved, falling to around 2.5% of GDP, and the EMEs surpluses have significantly fallen too. Although the surplus of oil exporters remained high, oil prices have started to decline from 2014, suggesting a probable downward trend of surpluses of oil exporters as well. The global natural rate, however, has not picked up from 2005. Bernanke (2015) explained this, by pointing out that the euro area surplus account has risen considerably, offsetting the improvements seen in the US and in most Asian emerging markets. He also suggests that this surplus, at least the one in the European periphery, is mostly due to cyclical factors and it is bound to decline. Thus, if oil prices remain low and the current account surplus of China and other Asian EMEs continues to drop, in the future r^n should be expected to rise moderately, according to Bernanke.

Shortage of safe asset. Short-term and long-term returns on government bonds have fallen all around the world. This decline appears to have started at the beginning of the 90s and it does not seem to be stopping. On the other hand, neither returns on corporate bonds nor returns on equity have experienced the same downward trend. As a result, the bond and equity risk premium has increased with time, which suggests that it is an increased demand for safety that caused the decline in the risk-free rates. Caballero *et al.* (2017) attributed this shift in preference to a variety of reasons: the ”savings glut” hypothesis, ”private label” safe assets, and the misguided ”safe haven” status given to weak sovereigns. Emerging markets started to increase their foreign exchange reserves in light of the Asian crisis of 1998 and to engage in precautionary savings due to high oil prices (savings glut). In response to this higher demand of safe assets, during the 2000s, the financial system financially engineered AAA-rated securitized instruments while weak sovereigns like Italy and Greece, perceived by naive investors as ”safe”[7], were partly able to satisfy the higher demand by issuing debt. Then, with the eruption of the Great Recession and the sovereign debt crisis, these ”pseudo-safe assets”[8] were not perceived riskless anymore and furthered the shortage of safe assets, as it is possible to see from Figure 1.5. It is this shortage that drives down the neutral rate, which is a riskless short-term interest rate.

The supply of safe assets has historically been concentrated in a small number of developed

[7] Reputation matters for a safe asset. Caballero *et al.* (2017) described a safe asset as: ”is a simple debt instrument that is expected to preserve its value during adverse systemic events [..], [it] can be transacted without much analysis or concern for adverse selection [..], [and] is safe if others expect it to be safe.”

[8] The term was introduced by Caballero, Farhi and Gourinchas in Caballero *et al.* (2017)

countries, while the demand is proportional to global output: in the past decades, the supply has fallen short of demand because the growth rate of advanced economies has been lower than the world's growth rate. As this trend is not likely to be reversed in the foreseeable future, the shortage of safe assets is here to stay and so are the downward pressures on the neutral rate.

A List of Safe Assets—Pre- and Post-Crisis

	Billions of US$		*% of world GDP*	
	2007	*2011*	*2007*	*2011*
US Federal government debt held by the public	5,136	10,692	9.2	15.8
Held by the Federal Reserve	736	1,700	1.3	2.5
Held by private investors	4,401	8,992	7.9	13.3
GSE obligations	2,910	~~2,023~~	5.2	~~3.0~~
Agency-and GSE-backed mortgage pools	4,464	~~6,283~~	8.0	~~9.3~~
Private-issue ABS	3,901	~~1,277~~	7.0	~~1.9~~
German and French government debt	2,492	3,270	4.5	4.8
Italian and Spanish government data	2,380	~~3,143~~	4.3	~~4.7~~
Safe assets	20,548	12,262	36.9	18.1

Source: Barclays Capital (2012). Data came from Federal Reserve Flow of Funds, Haver Analytics, and Barclays Capital.
Note: Numbers are struck through if they are believed to have lost their "safe haven" status after 2007. GSE means "government-sponsored enterprise." ABS means "asset-backed security."

Fig. 1.5: *The shortage of safe assets (Caballero et al. 2017)*

Following the same line of reasoning, Del Negro *et al.* (2017) estimated the effect of the convenience yield[9] on the natural rate of interest. Through two different methodologies (VAR and neoclassical DSGE), they are able to capture consistently low-frequency movements in the real interest rate and its drivers. Both approaches estimated that the natural interest rate was fairly stable at 2%-2.5% from the 1960s to the 1990s and then started its decline, reaching its trough at 1%.

With VAR, the authors were able to capture the secular trend of the convenience yield, which is split into two parts, one due to liquidity ($\bar{cy}_t^l$) and the other due to safety ($\bar{cy}_t^s$)[10]. The trend

[9] Krishnamurthy & Vissing-Jorgensen (2012) define the convenience yield as "the value that investors assign to the liquidity and safety attributes offered by Treasuries."

[10] If the two components of the convenience yield are covariance stationary, from the Euler equation for a safe/liquid asset, the secular trend in the natural rate of interest can be decomposed into $\bar{r}_t^n = \bar{m}_t - \bar{cy}_t^l - \bar{cy}_t^s$,

$\bar{cy}_t^s$ peaked in the eighties, then started to decline until the NASDAQ crash, when it started to increase again. According to their estimation, from 1998 the safety convenience yield has increased by 45bps. On the other hand, the trend $\bar{cy}_t^l$ has seen a steadily increase form the eighties, with an estimated increase from 1998 of 50bps. Much of this increase in liquidity was attributed to the financial crisis: firstly, because the GFC impaired the supply of liquid assets while raising its demand and then because the tightened regulatory framework required a higher amount of HQLA (high-quality liquid assets). This increase in the convenience yield explained one percentage point of the fall in r^n, which was estimated to be around 1.3%.

The DSGE approach confirmed these findings while shading light also on short-term variations of the natural rate of interest. Del Negro and his co-authors found that r^n, being a short-term interest rate, was very sensitive to the business cycle. For this reason, r^n plunged during the Great Recession, primarily due to shocks to the convenience yield and negative productivity shocks.

Secular stagnation. The significant trend decline in the neutral real rate is in part explained by a decline in economic growth, due to the impact of an ageing population on labour force growth (slower than in the past) and a slowdown in trend productivity growth (as a result of the slowdown in technological innovation). This decline in economic growth in advanced economies has led some scholars (Summers 2013; Gordon 2015 and 2016) to explain the low interest rate with the secular stagnation hypothesis, a concept originally formulated by Alvin Hansen in 1938. This phenomenon is described by Summers as "a prolonged period in which satisfactory growth can only be achieved by unsustainable financial conditions" that "may be the defining macro-economic challenge of our times". Summers emphasizes the role of a chronic weakness of demand (prominently due to depressed investments, because in the digital age the

where the first term is the stochastic discount factor and the other two are the liquidity and safety component of the convenience yield. See Krishnamurthy & Vissing-Jorgensen (2012).

economy is less capital intensive than it was in the past) in shaping the decline of the economic growth, whereas Gordon stresses the importance of supply-side factors. Slower potential output growth from the supply side - linked not only to slow productivity growth, but also to slower population growth and decreasing labour-force participation - diminishes the need for capital formation, and this, in turn, affects the aggregate demand and strengthens the decline in productivity growth. In the end, as stated by Gordon (2015), secular stagnation is not due exclusively to supply or demand factors, because both types of factors can interact and reinforce each other. For instance, a chronic weak demand lead to higher unemployment and if this become structural, human capital can diminish, and this, in turn, implies a decline in potential output.

The different sources of the decline in the interest rate discussed above, although treated separately, could be overlapping in explaining the fall in the natural rate of interest. Predicting the future path of the natural rate of interest depends heavily on the main causes of its decline. For example, if demographics factors or secular stagnation are the main sources of the decline, the low natural rate is likely here to stay for some time.

An interesting take on this issue is that of Rachel and Smith (2015). They also thought that the fall in the real interest rate – estimated to be around 450bps since the 1980s – across the world is a symptom of a fall in the global neutral rate, but they analysed the drivers of this fall both under the lens of a slowing global growth perspective and of a shift in saving and investment preferences. Through their analysis, they are able to account for 400bps of the 450bps fall: most of the decline in r^n (around 300 bps), is due to shifts in preference concerning savings and investments, while the remaining 100bps are due to low global growth. Thus, issues such as demographics, rising inequality and the saving glut – affecting the savings curve – or issues like the low price of capital goods, lower public investment and the rise in the spread between the risk-free rate and the rate of capital –affecting the investment curve –seem to be more prominent and should be corrected, if possible. According to Rachel and Smith, most of these effects are likely to be persistent and the global neutral rate is expected to remain around 1% in the future.

Finally, the decrease in the neutral rate can also reflect ”persistent headwinds” from the crisis: tighter underwriting standards, restricted access to credit, reduction of households’ debt, contractionary fiscal policy, and increased uncertainty about the economic outlook that limits the firms’ and households’ investment decisions (Yellen 2015).

All indications seem to confirm that neutral rates are expected to increase only very gradually in the future. Federal Reserve Chair Yellen stated that: ” [..] the equilibrium real federal funds rate is at present well below its historical average and is anticipated to rise only gradually over time as the various headwinds that have restrained the economic recovery continue to abate.” [11].

1.3 The flattening of the Phillips curve

Another phenomenon which has taken foot recently in many advanced countries is the looser responsiveness of wages and prices to economic slack. Empirically, this translates into a flattening of the Phillips curve, i.e. the relationship between inflation and unemployment. Figure 1.6 shows the slope of the Phillips curve in G7-economies from the 1980 to 2016: the correlation between unemployment and changes in inflation – which was negative in the 1980s, predicting prices and wages growth with reasonable accuracy – has become much flatter since 1995-1996, reaching zero after the Great Recession. This means that, on average, inflation can remain subdued even for historically low levels of the unemployment rate. For this reason, many economists recently have been debating whether the curve has disappeared in the US and Europe.

[11] Yellen (2015), Speech at the San Francisco Fed, March 27, 2015.

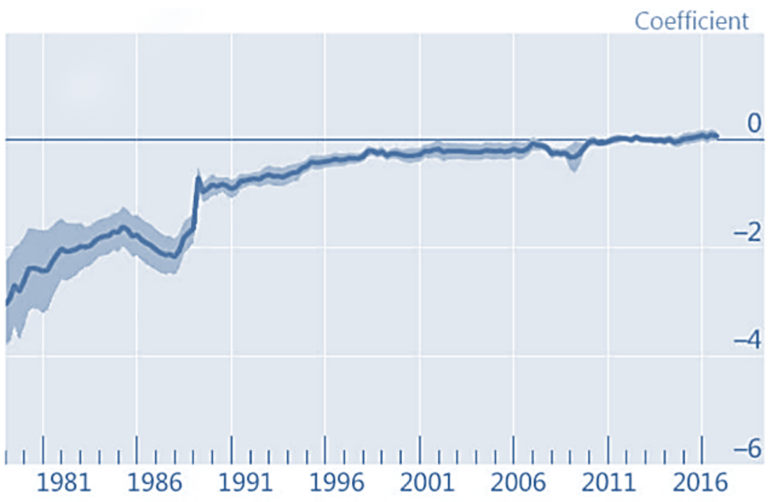

Fig. 1.6: *Time-varying Phillips curve slope. (Bank for International Settlements (2017))*

In 1958, A.W Phillips found a negative trade-off between unemployment and inflation by analysing data on UK unemployment and wages for the period 1861-1957. This suggests that when unemployment is low, workers have more bargaining power – since demand for labour is high, firms are more willing to offer competitive salaries to attract workers – and, as a result, wages tend to increase. In turn, wage costs for firms also rise and are ”passed along” to consumer through higher prices. However, this seems to be no longer the case: inflation response to unemployment is much more muted, as experienced during the GFC (at least in the US). Even policymakers were puzzled by this response: ”The surprise is that [inflation] has fallen so little, given the depth and duration of the recent downturn. Based on the experience of past severe recessions, I would have expected inflation to fall by twice as much as it has.”[12]

It was exactly the fact that in spite of a very high unemployment rate, inflation did not plummet during the GFC that caught the attention of researchers. They wondered what happened to the negative relationship between inflation and unemployment, which during the Great De-

[12] Williams in 2010 during the ”Presentation to Joint Meeting of the San Francisco and Salt Lake City Branch Boards of Directors.”

pression (1930-1932) caused a cumulative deflation of 25%. In his Presidential Address, Hall (2011) even called for a "fundamental reconsideration of models in which inflation depends on the measure of slack in the economic activity."

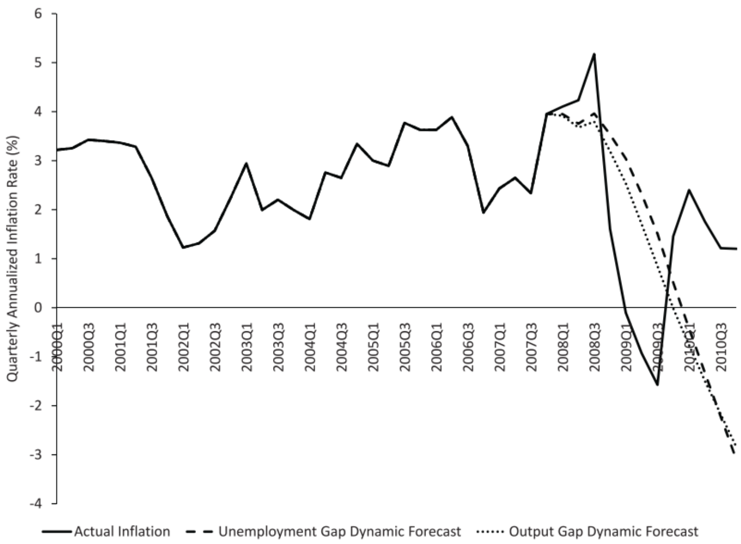

Fig. 1.7: *Forecasts of CPI inflation for 2008-2010 (Ball and Mazumder, 2011)*

Ball and Mazumder (2011) were among the first to study US inflation dynamics during the GFC and try to explain the absence of deflation predicted by the accelerationist Phillips curve. Their approach consisted in estimating an accelerationist Phillips curve[13] with quarterly data for the period 1960-2007 and forecasting inflation for the years 2008-2010 based on the estimated regression. According to their estimates, the Pre-2008 Phillips curve predicted deflation, as it is possible to see from the dashed line in Figure 1.7. However, the model seemed to imply that the slope had not remained constant over the entire sample. Once they allowed the slope of the Phillips curve (α) to vary[14], they found that it co-moved closely with the level and variance of inflation. This implied that, when inflation was higher in the 1970s, the Phillips curve was

[13]Ball and Mazumder conventionally assumed inflation expectations based on past inflation and a curve of this type: $\pi_t = \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha(u - u*)_t + \varepsilon_t$

[14]Now the slope α depends on time and it follows a random walk: $\alpha_t = \alpha_{t-1} + \eta_t$.

steep, but when inflation became low and stable (around the 90s), the Phillips curve became much flatter. This finding seems to be in line with Ball, Mankiw and Romer (1988), who suggested that the slope of the Phillips curve depended on the level and variance of inflation. In the presence of costly nominal price adjustments, firms adjust prices more frequently only for high levels of inflation, making the aggregate price level more flexible and steepening the slope of the Phillips curve. Thus, according to Ball and Mazumder, the high degree of nominal price stickiness, coupled with low inflation, is the main reasons for which the Phillips curve has flattened. A few years later, the International Monetary Fund (IMF) reached a similar conclusion. By estimating an unemployment-based Phillips curve for twenty-one developed countries, this study also found that the effect of the unemployment gap on inflation has declined over time since prices' adjustment costs deter firms from changing frequently their prices when inflation is low.

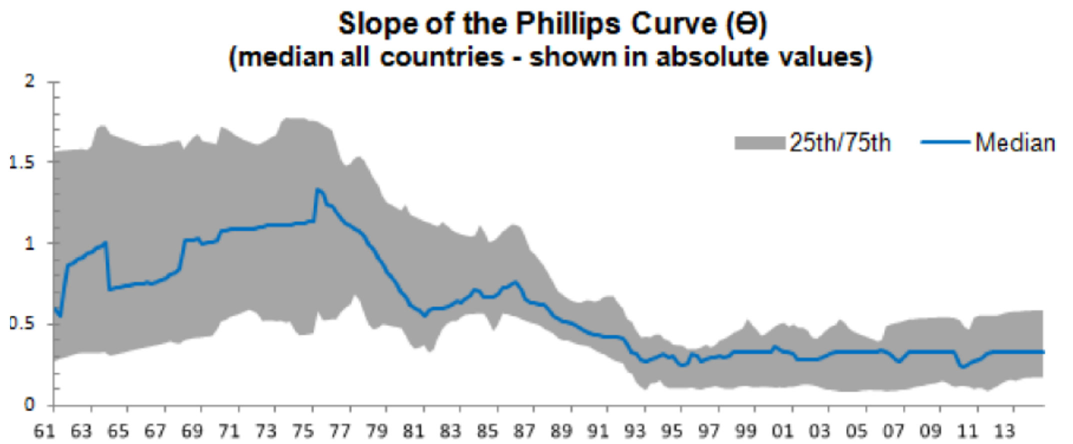

Fig. 1.8: *Median estimate of the slope of the Phillips curve (Blanchard et al. (2015))*

Blanchard, Cerutti and Summers (2015) estimated for 20 advanced economies an accelerationist Phillips curve – defined as a relation between inflation, expected and lagged inflation and the unemployment gap, – over the past 50 years. Firstly, they found that the coefficient on long-term expected inflation has risen over time. Secondly, they also confirmed that the slope of the Phillips curve has substantially declined from the beginning of the sample but the estimated coefficient of the slope is still significant for 15 countries. Moreover, they found that the decrease had started around the mid-1970s and has remained roughly stable since the early 1990s (Figure 1.8). In other words, the flattening of the Phillips curve does not appear to be a legacy of the Great Recession. Blanchard (2016) suggests that over time the Phillips curve moved away from its accelerationist version and now resembles the Phillips curve of the 1960s (”level Phillips curve”), where the unemployment rate affects the level rather than the change in inflation. Blanchard observes that a low unemployment-inflation trade-off implies that the unemployment rate can remain below its natural rate for long before inflation rises significantly, which can expose the central banks to political pressures to keep monetary policy accommodative at least until it sees "the whites of inflation’s eyes".

Del Negro, Giannoni and Schorfheide (2015) have a different perspective on the flattening of the Phillips curve. First of all, they defend the ability of DSGE model, and the New Keynesian Phillips curve, in successfully explaining the behaviour of inflation during the Great Recession. In response to the criticism posed by Hall (2011) and Ball and Mazumder (2011), they showed how a DSGE model, similar to Smet and Wouters (2007) but extended to include financial frictions, successfully predicted a severe contraction of economic activity along with a moderate and persistent decline in inflation. As a matter of fact, the model largely captured low- and medium-frequency movements of inflation from 1964 to the aftermath of the Great Recession. Secondly, they show how inflation was largely determined by fundamental inflation, defined as the discounted sum of future marginal costs. Although marginal costs sharply declined during the GFC, they were expected to revert back to their steady state in the future, leading to a fall in inflation but not as severe as deflation. Del Negro and his co-authors also highlighted how monetary policy was still able to anchor inflation since marginal costs are more affected by

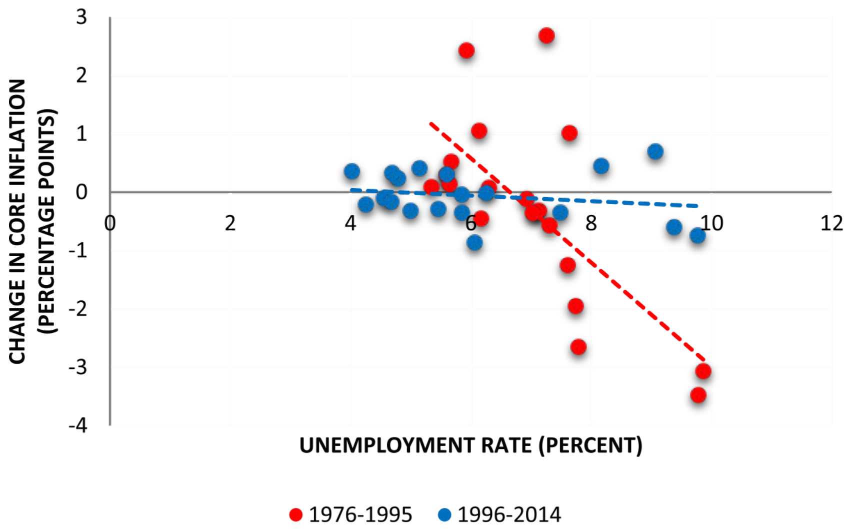

Fig. 1.9: *The accelerationist Phillips curve (Kiley (2015))*

policy when the Phillips curve is flatter.

Some scholars deem that the successful monetary policy (monetary policy credibility) in the ”inflation targeting era” has led to the flattening of the empirical Phillips curve. During this period inflation has generally been lower, less volatile and anchored to the stated inflation targets (Laxton and N'Diaye 2002, Kiley 2008, Boivin, Kiley and Mishkin 2010). Bernanke (2010), for example, stated that occurrences such as high inflation and deflation are much more unlikely with the higher degree of anchoring of expectations. This would explain why deflation had not taken places even when unemployment was sky-rocketing during the GFC. Kiley (2015) was sceptic: ”this anchoring is probably insufficient to explain the limited decline in inflation following the rise in unemployment in 2008 and 2009: [looking at Figure 1.9] both expected and actual (core) inflation were in the neighborhood of 2 percent during those years, and hence the fact that inflation remained near this level when unemployment was near 10 percent (as can be seen by the small change in inflation when unemployment was near 10 percent in the blue dots) points to factors other than anchored inflation expectations.” Ball and Mazumder (2011) also discarded this hypothesis, by pointing out that the slope of the Phillips curve, when derived from microeconomic foundations, is determined by the slope of marginal cost and the frequency of price adjustments. They argue that anchoring of expectations can affect the inflation expectations but not the unemployment coefficient.

The weak trade-off between inflation and unemployment may be in part due to globalisation (Auer and Sauré 2013, Auer, Borio and Filardo 2017). Large multinational companies can access to labour force across the world and not only in the domestic country, thus lifting the constraints of labor supply in any one country (firms may hire more abroad rather than increasing domestic wages). IMF (2006) estimates that globalisation can account for more than half of the decline in the sensitivity of prices to domestic output[15], while improved monetary policy credibility and the low inflation environment account for the rest. Guilloux-Nefussi (2015) shows that globalisation has indeed contributed to the flattening of the Phillips curve through a general equilibrium model. She shows that, while globalisation increases the number of goods available and thus reduces market power, it also increases ”self-selection” of high productivity firms with larger market share. In her estimates, the first effect, which would cause the Phillips curve to steepen, is offset by the second, increasing nominal rigidities and thus flattening the Phillips curve. Much research (Auer, Borio and Filardo 2017, Zhang 2017) shows that the greater international economic interconnectedness over recent decades has been changing inflation dynamics. In particular, the expansion of global value chains (cross-border trade in intermediate goods and services) has been a key factor behind the growing importance of the global output gap in determining domestic inflation.

Another factor which has determined this flattening is the reduction in the bargaining power of workers (Hawksworth and Durham 2017). This decrease in worker power seems due to the following factors:

[15] IMF (2006) includes as a measure of economic slack the output gap rather than the unemployment gap.

1. the fall in the unionization of the workforce from 38% in 1990 to 23% in the middle of 2016 (and considerably lower than this in the private sector);

2. a strong increase in the flexibility of modern work (strong increase in part-time and temporary working) over the last decades.

These changes have weakened the worker bargaining power as worker are less able to negotiate higher wages when the unemployment rate is low. A number of factors are likely to have produced these shifts in the Phillips curve, but there is no consensus about the factors that have determined this flattening. The empirical literature based on macroeconomic data is not conclusive about the main factors which are behind the flattening of the Phillips curve observed in the industrial countries.

1.4 The implications for monetary policy

The concept of the real equilibrium interest rate is very important because it provides a benchmark for defining the stance of monetary policy: contractionary if the policy interest rate is above the natural rate and expansionary if it is below this level. Because the existence of the zero lower bound (ZLB), too low a neutral interest rate limits the effectiveness of standard monetary policy. The low level of neutral rate of interest – if considered as persistent in the future – has critical implications for monetary policy (Fisher 2016; Constâncio 2016; Blanchard, Dell'Ariccia and Mauro 2010; Summers 2014). The lower the level of the natural rate, the lesser 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)[16].

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

The ability of monetary policy to reach its target 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 slowdown. The Phillips curve is one key factor in the central bank's decision-making on interest rates (in particular, in the United States) because it is a tool to estimate inflation expectations and changes in the long-run equilibrium rate of unemployment (NAIRU or the non-accelerating inflation rate of unemployment), defined as the lowest level of the unemployment rate that can be reached without determining rises in inflation.

The uncertainty about determinants of the flattening of the Phillips curve does not allow to fully assess its policy implications, because they are strictly linked to its underlying causes and different causes leading to opposing conclusions.

Irrespective of the causes, the flattening of the Phillips curve implies a certain loss of information that can stem from inflation fluctuations. Gordon (2013) argued that in some exceptional case, the flatter curve might prevent the calculation of the NAIRU, leaving central bankers "steering the economy in a fog with no navigational device to determine the size of the unemployment gap".

In addition, to the challenges of a worsening of the output-inflation trade-off and a steady decline in the natural interest rate, the future monetary policy framework in advanced countries should take in account the legacy of the GFC. The global crisis has radically changed the way in which monetary policy was conducted and implemented. Starting from 1990, in most advanced countries the monetary policy strategy adopted was the inflation targeting regime. According to Svensson (2008) this approach is based on three elements: 1) an announced numerical target of inflation; 2) monetary policy decisions (in terms of changes in short term interest rates) to steer actual inflation toward the numerical target; 3) a high level of transparency and accountability. Prior to the crisis, the performance of this approach was widely considered a success. Empirical evidence proves that all countries in which this regime was adopted have experienced a decline in both the level and variability of inflation and a better anchoring of inflation expectations. With the outbreak of the global crisis, this regime has come into criticism, in particular with regard to its ability to fight deep recessions. The adverse shocks that hit the economy during the crisis have led the interest rate operational target of central banks to zero, making the conventional expansionary monetary policy ineffective. When the zero lower-bound problem occurred, central banks were forced to enlarge the toolkit used in the monetary strategy (asset purchases, forward guidance and negative rates), becoming more innovative.

As stated by Mishkin (2017), ”notwithstanding the support for the flexible inflation targeting framework is not weakened by the lessons from the financial crisis, the lessons do suggest that the details of how flexible inflation targeting is conducted, and of what is meant by flexibility, need to be rethought”, with regard in particular to 1) the choice of the inflation target and 2) the convenience of pursuing some form of history-dependent targeting.

Chapter 2

Literature Review

2.1 Monetary policy in a low natural rate environment

As suggested in chapter 1, the likelihood of hitting the zero lower bound is much higher than previously thought, mostly because of the decline in the natural rate of interest. One important implication is that 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 as it is, is the right way to go.

There seem to be two different schools of thought on the matter: evolution or revolution. The first one argues for changes in the present monetary policy framework, suggesting in particular 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 for an inflation targeting regime.

Raising the inflation target seems like the simplest solution to prevent a higher incidence of the ZLB, as it would not require a deep 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 in the research literature. Moreover, even if 2% was deemed as the optimal target in the 1990s, this does not necessarily imply that it is still the right one in the post-2008 environment. A recent survey (Diercks 2017) analysed the existing literature on the optimal inflation target and showed the lack of consensus among academics: out of 100 studies, 31 suggested the optimal rate was negative, 50 advocated for a zero inflation and 19 supported positive inflation. Why then was 2% chosen as the target to begin with, and not zero, as half of the studies suggested? This is partly because of the upward bias in consumer price indices, which implies that inflation tends to be overestimated: a target of 2% is therefore probably not far away from zero. Krugman (2014) provided an alternative justification and explained it with the two zeros: the first one is that nominal interest rates cannot be negative since cash provides a zero-return alternative, and the second one is because of downward nominal rigidities. According to Krugman, these were the main reasons explaining why a positive target was established in the 90s and why 2% was considered high enough to deal with the two zeros.

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 exhibits history-dependence and can be implemented by targeting the price level or, to a lesser extent, nominal GDP; history-dependence implies that if the inflation target has been undershot in the recent past, monetary policy should strive to overshoot it in the near future.

An inflation targeting strategy is not history-dependent because it tries to reach its monetary policy target without taking into account what has happened in the past; “it treats bygones as bygones”, meaning that the past undershooting or overshooting of the inflation target does not affect the current stance of monetary policy.

2.2 Is inflation targeting an idea past its sell-by date?

A low neutral rate limits the scope of monetary policy in deflationary recessions. After the financial crisis, the strategy of inflation targeting - viewed previously as the “norm” for modern central banking – has experienced a severe blow to the confidence in its effectiveness.

According to Blinder (2013), “Signs of inflation targeting have been somewhere between invisible and absent ever since the crisis erupted. Other concerns, such as financial and macroeconomic stability, and especially boosting economic growth, appear to have trumped inflation. [. . .] In many countries, inflation ran below target, in some others, above. No one seemed to care much, though the long-run inflation targets remained intact as nominal anchors”.

Two main arguments were used by opponents of inflation targeting: 1) its inability to prevent the crisis, focusing too much on inflation and too little on financial stability; 2) its inability to fight the recession triggered by the crisis and to accelerate the recovery in economic activity and inflation.

The intrinsic weakness of inflation targeting has been exposed by Woodford (2003): taking as a benchmark the optimal policy under commitment, Woodford noted that strategies like price level or, to a lesser extent, nominal GDP targeting outperform inflation targeting as they exhibit history-dependence.

Price level targeting was an object of discussion long before the Great Recession. Price stability has been the primary goal of monetary policy for the last decades but some interpreted price stability as price level stability rather than low and stable inflation. In the first case, the implied monetary policy regime would be price level targeting while in the second one the regime corresponds to inflation targeting. The main difference between the two is that in the former the price level is stationary while in the second it drifts and its variance grows without bound.

This is why some economists begun discussing price level targeting (PLT) in the nineties, right at the time inflation targeting (IT) was being adopted in most industrialized countries. However, at the time IT was considered to be superior since PLT was thought to cause unnecessary output gap volatility and thus worsen the trade-off between inflation and output gap.

The strategy proposed by Nessén and Vestin (2005), average inflation targeting (AIT), is considered to lie in between price-level targeting and inflation targeting because it still belongs to the current framework but displays a certain degree of history dependence which characterises PLT. This strategy aims to reach the inflation objective over a given time frame, instead of in a single period as IT so that the average of inflation is on target. The degree of gradualism of this strategy depends ”on the width of the window used when calculating the average inflation rate”.

2.3 A higher inflation target to escape the ZLB

After the crisis economists started to reconsider the issue of whether a 2% inflation target was appropriate, which was perceived to be too low to deal with the ZLB constraint (Blanchard *et al.* 2010). Many argued that, although it proved sufficient in the past, when liquidity traps were considered rare events and occurred infrequently, and nominal rates were high enough to be sizeably cut when recessions materialized, in the post-recession environment it left monetary policy too exposed to liquidity traps.

Ball (2013) gauges the risk of zero-bound episodes in the US by analyzing the behaviour of interest rates in past recessions. Table 2.1 shows how most of these recessions would have resulted in hitting the ZLB, had a 2% inflation target, which the U.S. Federal Reserve adopted only in 2012, been in place throughout the sample.

Recession	Inflation Rate at Start	Maximum Unemployment Rate	Minimum Federal Funds Rate	
			Nominal	Real
1960:4 -1961:2	2.00	7.10 (1961:05)	1.17 (1961:07)	-0.14 (1961:07)
1969:12 -1970:11	5.91	6.10 (1970:12)	3.29 (1972:02)	-2.31 (1971:02)
1973:11 -1975:3	4.73	9.00 (1975:05)	4.61 (1977:01)	-5.80 (1975:03)
1980:1 -1980:7	11.97	7.80 (1980:07)	9.03 (1980:07)	-4.13 (1980:06)
1981:7 -1982:11	11.14	10.80 (1982:11)	5.85 (1986:10)	1.71 (1986:09)
1990:7 -1991:3	5.11	7.80 (1992:06)	2.92 (1992:12)	-0.55 (1993:02)
2001:3 -2001:11	2.61	6.30 (2003:06)	0.98 (2003:12)	-0.96 (2001:12)
2007:12 -2009:6	2.44	10.00 (2009:10)	0.07 (2011:07)	-2.19 (2012:01)

Fig. 2.1: *Recessions and interest rates*

As nominal rates cannot become negative,[1] a zero-bound episode would occur whenever the negative real rate equals the rate of inflation. Since inflation falls during a recession, Ball assumed the real lower bound to be 1% and found that in the past recessions the ZLB would have been hit in 4 cases out of 8, with one additional near-miss in 1990-1991. The 4% inflation proposed by Ball would instead imply that the ZLB constraint would have been binding only in 2 cases out of 8. Thus, a higher inflation rate could be beneficial as it would lower the probability of incurring a liquidity trap.

A more recent study focuses on the relationship between the neutral real rate of interest (r^n) and the optimal inflation target (Andrade *et al.* 2018). The authors analyse the hypothetical response of policymakers to the decline in the natural rate of interest when adjusting the inflation target is their only option. They discover there is a less than one-to-one inverse relationship between r^n and inflation and find that a decrease of 1% in the natural interest rate warrants an

[1]The recent experience of Denmark, Switzerland, Sweden and the euro area shows that this statement is not generally valid: apart from retail deposits, the effective lower bound is actually below zero, due to storage, insurance and security costs banks must bear if they decide to turn central bank reserves into banknotes.

increase in the optimal inflation target of 0.9%.

Another argument in favour of raising the inflation target is given by downward nominal rigidities, i.e. the fact that nominal wages are rarely cut as they are unpopular both to employers and employees. This rigidity is particularly relevant in the current low inflation environment because it prevents real wages to fall as much as needed to keep unemployment low. Krugman (2014) reports for instance that debtor countries in the (Ireland, Italy, Portugal, and Spain) did not experience substantial reductions in compensation in spite of quite severe unemployment rates during the crisis. This failure of wages to downwardly adjust was a key factor in causing the unemployment crisis in the Eurozone and it is one of the reasons why the Great Recessions had such lasting effects. A higher inflation target would be beneficial since it allows employers to cut real wages without affecting nominal ones, thus reducing inefficient unemployment. Also, the negative effects of downward nominal rigidities are less severe when inflation is high enough. An interesting proposal was made on this matter by Stephanie Schmitt-Grohé and Martín Uribe (2013), who suggested, when recovery after the Great Recession was slow, to temporarily raise the inflation target in the EU in order to achieve full employment once again. Furthermore, other studies show that inflation "greases the wheels", i.e. leads to lower unemployment by allowing greater wage flexibility in response to negative shocks. In the US the optimal range of inflation which minimizes unemployment is between 1.5% and 4% (Akerlof *et al.*, 2000), while in the EU the optimal inflation rate is estimated to be around 4% (Wyplosz 2000). This is closely linked to the so-called money illusion, which is the tendency of people to confuse increases in nominal wages due to inflation with higher purchasing power. Money illusion exists for a very low level of inflation (1-2%) and dissipates after a certain threshold.

However, inflation has costs that should be thoroughly assessed before deciding to adopt a higher target. Inflation undermines the operation of the price system in achieving an efficient allocation of resources and should, therefore, be kept at a level consistent with price stability. According to Greenspan, “price stability may be defined as that state in which expected changes in the general price level do not effectively alter business or household decisions” (Greenspan, July 1996 FOMC meeting). Inflation is not salient, i.e. it does not affect consumption or financial decisions when it equals zero if properly measured or is somewhat below 3% according to available price indices (Mishkin 2017). The proposed higher target would exceed this threshold and would imply the risk of inflation becoming salient. One immediate consequence would be a decrease in cash, with potential overinvestment in the financial sector and difficulties in long-term financial planning. Other distortionary effects would occur in a non-indexed tax system and, more generally, when contracts are set in nominal terms. Furthermore, "menu costs", i.e. continuously updating prices due to rising inflation, will be larger the higher the inflation rate (Fischer and Modigliani 1978; Driffill *et al.* 1990).

The major concerns about a higher inflation target though regard inflation variability and price dispersion. Inflation variability seems to be positively correlated with higher inflation: in a sample of 105 countries, an increase of 1% in the average inflation rate raises by half a percentage point the volatility of annual inflation (Cecchetti 2017). An increase in the level of inflation affects trend inflation and thus long-term uncertainty, which makes policy less effective and leads to output volatility (Cecchetti and Ball 1990). Furthermore, a consistent body of literature finds that price dispersion increases with inflation, worsening the allocation of resources and lowering welfare (Sheshinski and Weiss 1977; Benabou 1988 and 1992; Head and Kumar 2005).

More recently, these findings have been questioned. A micro-based analysis on the cost of inflation during the past four decades has shown that price dispersion was not significantly higher during the Great Inflation (Nakamura *et al.* 2016), while a macroeconomic model found that the relationship between inflation and price dispersion is negative when sales are included in the data (Sheremirov 2015). Finally, less volatile inflation and more predictable monetary policy are not always optimal: they can encourage risk-taking, reducing uncertainty and inducing asset managers to underestimate risk (Gambacorta 2009).

The major risk in raising the target is, however, that of jeopardizing the credibility of central banks. One of the greatest achievements in monetary policy is the anchoring of inflation expectations around 2%, which has prevented even in the aftermath of the GFC a return to deflation as occurred in the Great Depression. It is true that inflation has been below target since 2008, but it averaged 1.7% since the mid-90s, so not that far from the actual target. The ECB had (and still has) more difficulties in bringing up consumer price dynamics and even experienced a brief period of negative inflation between 2014 and 2015 but successfully avoided deflation. This also raises the question of how it is possible to switch to a higher target when the current one has been undershot consistently in the recent past.

Credibility concerns come into play when dealing with public perception: if the target has been changed once, what prevents central banks from changing it again? The public is likely to see this choice as a weakening of the commitment not only to the 2% target but to any target, paving the way to a de-anchoring of expectations. Moreover, according to Bernanke and Mishkin, it is far more difficult to tie down expectations at 4%.

In the US, those who argue for a higher target point out that credibility has nothing to do with the numerical target itself but depends on the ability of central banks to fulfil their mandates. Hence, it is much more dangerous for credibility to cling to the current target (which they perceive as arbitrary) if this is no longer achievable.

2.4 The costs of a non-zero inflation target

Higher average inflation and nominal interest rates would reduce the probability of hitting the effective lower bound, giving more room to monetary policy to offset deflationary shocks during a recession and subtracting from fiscal policy some of the strain to stabilise aggregate demand during a crisis. Another common motivation for supporting a positive and sufficiently high inflation target is downward nominal wage rigidity, a feature of developed economies that is usually found in the data: if it is socially unacceptable that workers' compensation decreases, then positive inflation rates are a way to facilitate the downward adjustment of real wages required to adjust to negative shocks. An additional feature that could potentially lead to higher rates of optimal inflation is model uncertainty: if the monetary authority is uncertain about some parameters and plausible values lead to much higher frequencies of hitting the ELB or raise the output costs of being at the ELB, then it might find convenient to insure against bad outcomes and allow for a higher π^*.[2] Finally, higher levels of inflation are usually associated with more volatile inflation, which makes economic planning more difficult for households and firms.

However, these reasons by themselves are not enough to justify setting a higher inflation target in the future, as inflation is costly. Ascari and Sbordone (2014) provide a detailed analysis of the problems generated by higher trend inflation.[3] They show that the choice of the central bank target affects (i) the level of steady-state output, as positive trend inflation implies a violation of the natural rate hypothesis; (ii) the dynamics of the standard New Keynesian model and the trade-offs confronted by the central bank; (iii) the size of the region of the parameter space that induces a unique rational expectations equilibrium.

[2] See Coibion *et al.* (2012).

[3] The analysis of the cost of inflation that follows draws heavily from Ascari and Sbordone (2014). They use the expression 'trend inflation' as a synonym of target inflation, as in the long run inflation is controlled by the central bank and converges to the desired level.

To see why the steady-state output is lower the higher the inflation target, one has to focus on price dispersion, which in New Keynesian models is the main source of inefficiency. Price dispersion affects the quantity of aggregate output that can be obtained by using a given quantity of aggregate employment. If the production function for firm i is $Y_{i,t} = A_t N_{i,t}$, the aggregate labour demand is:

$$N_t = \int_0^1 N_{i,t} di = \int_0^1 \frac{Y_{i,t}}{A_t} di = \frac{Y_t}{A_t} \int_0^1 \left(\frac{P}{P_t} \right)^{-\varepsilon} di = \frac{Y_t}{A_t} s_t, \tag{2.1}$$

where $s_t \equiv \int_0^1 \left(\frac{P_{i,t}}{P_t} \right)^{-\varepsilon} di \geq 1$ is a measure of price dispersion.[4] Aggregate output is

$$Y_t = \frac{A_t}{s_t} N_t. \tag{2.2}$$

Price dispersion increases the amount of labour that is needed to produce a unit of output: a rise in s_t basically plays the role of a negative productivity shock.

Price dispersion s_t can be written in recursive form as follows:

$$\begin{aligned} s_t &= \int_0^1 \left(\frac{P_{i,t}}{P_t} \right)^{-\varepsilon} di = \frac{1}{P_t^{-\varepsilon}} \int_0^1 P_{i,t}^{-\varepsilon} di = \frac{1}{P_t^{-\varepsilon}} \left[(1-\theta) P_{i,t}^{*-\varepsilon} + \theta \int_0^1 P_{i,t-1}^{-\varepsilon} di \right] \\ &= (1-\theta) \left(\frac{P_{i,t}^*}{P_t} \right)^{-\varepsilon} + \theta \left(\frac{P_{t-1}}{P_t} \right)^{-\varepsilon} \int_0^1 \left(\frac{P_{i,t-1}}{P_{t-1}} \right)^{-\varepsilon} di = (1-\theta) p_{i,t}^{*-\varepsilon} + \theta \Pi_t^{\varepsilon} s_{t-1}. \end{aligned} \tag{2.3}$$

The steady-state value of price dispersion is therefore:

$$s = \frac{1-\theta}{1-\theta \Pi^{*\varepsilon}} p^* = \frac{1-\theta}{1-\theta \Pi^{*\varepsilon}} \left(\frac{1-\theta \Pi^{*\varepsilon - 1}}{1-\theta} \right)^{\frac{\varepsilon}{\varepsilon-1}},$$

[4] Schmitt-Grohé and Uribe (2005) neatly show that $s_t \geq 1$. The proof is quite simple. Since the price level is: $P_t = \left[\int_0^1 P_{i,t}^{1-\varepsilon} di \right]^{\frac{1}{1-\varepsilon}}$, it follows that $1 = \left[\int_0^1 \left(\frac{P_{i,t}}{P_t} \right)^{1-\varepsilon} di \right]^{\frac{1}{1-\varepsilon}}$. Defining $v_{i,t} \equiv \left(\frac{P_{i,t}}{P_t} \right)^{1-\varepsilon}$, it is easily seen that $1 = \int_0^1 v_{i,t} di = \left[\int_0^1 v_{i,t} di \right]^{\frac{\varepsilon}{\varepsilon-1}}$. The price dispersion index s_t can be also written as $s_t = \int_0^1 v_{i,t}^{\frac{\varepsilon}{\varepsilon-1}} di$. Jensen's inequality implies that $1 = \left[\int_0^1 v_{i,t} di \right]^{\frac{\varepsilon}{\varepsilon-1}} \leq \int_0^1 v_{i,t}^{\frac{\varepsilon}{\varepsilon-1}} di = s_t$, which proves that $s_t \geq 1$.

which shows that the value of s is increasing in the average duration of prices (θ), the elasticity of substitution among goods (ε) and the inflation target ($\Pi^* - 1$).[5] The explanation of these results is quite straightforward. First, if all prices could be adjusted immediately, there would be no price dispersion; on the contrary, when θ is high so is s. Second, a large elasticity of substitution implies that the production of intermediate goods is allocated more inefficiently among firms. Third, the higher trend inflation, the larger the gap between the price of the firms that can adjust and the price of those that cannot.

To assess the impact of price dispersion on steady-state output, it is necessary to substitute N_t out of equation (2.2). The real marginal cost is equal to $mc_t = \frac{W_t}{A_t P_t}$ and the real wage is $\frac{W_t}{P_t} = \chi N_t^{\eta} C_t^{\sigma} = \chi N_t^{\eta} Y_t^{\sigma}$.[6] Taking the steady-state value of the previous two equations and rearranging, (2.2) becomes

$$Y = \left(\frac{A^{\eta+1}}{\chi} \frac{mc}{s^{\eta}} \right)^{\frac{1}{\eta+\sigma}} = \left(\frac{A^{\eta+1}}{\chi} \frac{1}{s^{\eta} \mu} \right)^{\frac{1}{\eta+\sigma}}, \tag{2.4}$$

where $\mu = \frac{1}{mc}$ is the mark-up charged by firms on (real) marginal costs. The mark-up also is inversely related to price dispersion. The intuition for this result becomes apparent from the following decomposition of the mark-up:

$$\mu \equiv \frac{P}{MC} = \left(\frac{P}{P^*} \right) \left(\frac{P^*}{MC} \right). \tag{2.5}$$

The first term, $\frac{P}{P^*}$, measures the gap between the price of firms that are not able to reset and the price of those that are; the second term, $\frac{P^*}{MC}$, is the ratio between the newly adjusted price and marginal cost. $\frac{P}{P^*}$ is lower the higher target inflation because the latter erodes the relative price

[5] $\Pi_t \equiv P_t / P_{t-1}$ is the gross inflation rate and $\pi_t \equiv \frac{P_t - P_{t-1}}{P_{t-1}} = \Pi_t - 1$ is the inflation rate. Accordingly, $\pi^* \equiv \Pi^* - 1$.

[6] In equilibrium, the real wage times marginal utility of consumption is equal to the disutility of labour. It is assumed that the utility function is of the following type: $u(C_t, N_t) = \frac{C_t^{1-\sigma}}{1-\sigma} - \chi \frac{N_t^{1+\eta}}{1+\eta}$. The final equality in the equation for the real wage exploits the fact that goods market equilibrium requires that $Y_t = C_t$.

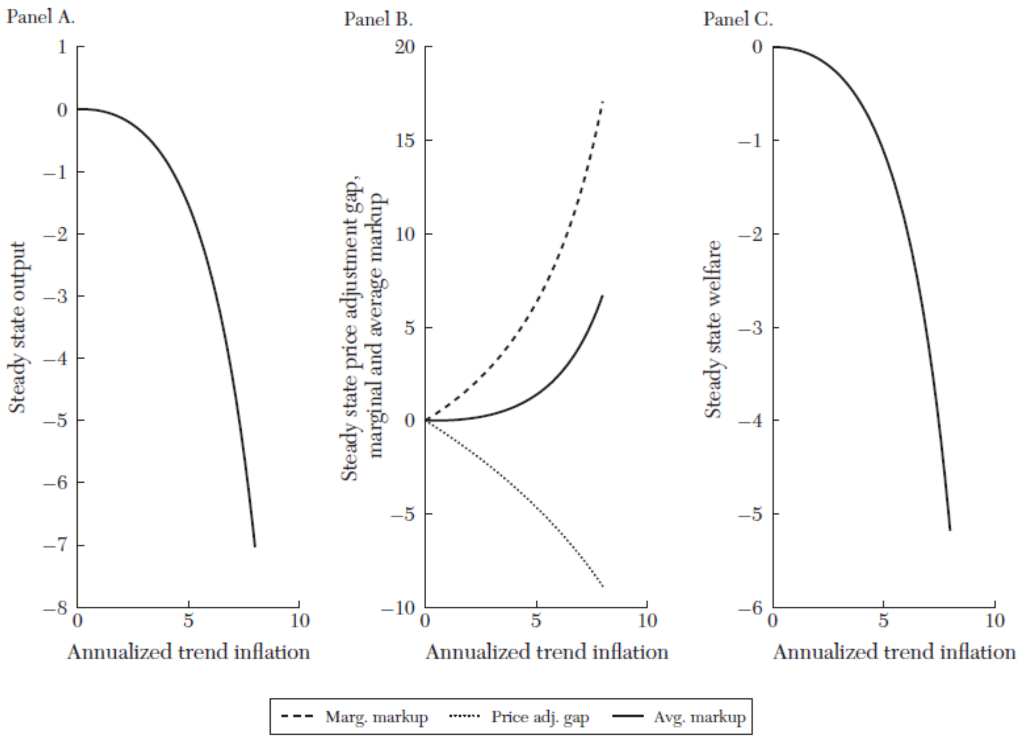

Fig. 2.2: *Trend inflation and steady-state output and welfare*

of firms unable to reset; $\frac{P^*}{MC}$ varies in the same direction as π^*, because firms need to adjust more when inflation is high, anticipating that they may not be able to reset their price in future periods. The second effect, in general, more than offsets the first, so that the mark-up increases when the inflation target is set higher.

As shown by equation (2.4), a higher inflation target affects steady-state output through three channels: (i) the level of technology A, which gets smaller; (ii) price dispersion s, which gets higher; (iii) the mark-up μ, which widens.

Ascari and Sbordone (2014) show that in the standard New-Keynesian model the negative effect of trend inflation on steady-state output through price dispersion is usually quite large.

Panel A in Figure 2.2 shows that moving from a 2% to a 4% inflation target can reduce long-run output by about 1.5%; Panel B indicates that the mark-up effect is negative but limited, at least for $\pi^* \leq 5\%$; Panel C makes apparent that steady-state welfare is also strongly decreasing with trend inflation, because a higher π^* reduces consumption and increases the amount of labour that is needed to produce a given amount of output.

Positive trend inflation affects not only steady-state output and welfare but also the way the economy responds to shocks. Ascari and Sbordone (2014) show that the Phillips curve becomes flatter when the inflation objective of the central bank is greater than zero and the monetary transmission mechanism changes accordingly: in response to a positive monetary policy shock, inflation falls less, as the Phillips curve is flatter when $\pi^* > 0$, and the policy rate increases more, depressing the output gap. In general, trend inflation tends to step up the persistence – and in some cases the volatility – of macroeconomic variables.

Finally, Ascari and Ropele (2009) show that positive trend inflation causes the determinacy region to shrink. Two main policy implications emerge from their analysis: first, when $\pi^* > 0$ inflation expectations are destabilised and hence less well-anchored; second, monetary policy should respond more to inflation deviations from target and less to output fluctuations.

In conclusion, neither the benefits nor the costs of a higher inflation target have been clearly and unambiguously quantified in the recent 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 even if they are small in any given year, they add up. Bernanke, for example, while agreeing that this proposal has some merits, adds that it is not the most effective way to deal with the ZLB problem. Nonetheless, this proposal has gained foothold in the aftermath of the crisis and even former Fed Chairman Janet Yellen stated that "this is one of the most important questions facing monetary policy around the world in the future, and we very much look forward to seeing research by economists that will help inform our future decisions on this" (Yellen 2017).

2.5 Svensson: price-level targeting as a free lunch

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 trade-off was viewed to be due to the history-dependence of price level targeting, which implies that if the price target was overshot in the past, it must be undershot in the future in order to bring back the level of prices to its original value: this generates a higher variability in inflation than what IT displays and, if nominal rigidities are presents, it also entails a higher output variability. Svensson instead proved that in a backward-looking New Classical model satisfying certain conditions, it was indeed possible to improve inflation variability without worsening output variability.

He considered a model in which society's preferences are described by a quadratic loss function that depends on the deviation of inflation (π_t) and output (y_t) from their target values:

$$L_t = \frac{1}{2}\left[(\pi_t - \pi^*)^2 + \lambda\,(y_t - y^*)^2\right]. \tag{2.6}$$

The above function is interpreted as an approximation to the level of expected utility of the representative household in the rational expectations equilibrium which justifies the central bank's concern for price stability (Woodford 2003). Society delegates an inflation target or price level target to the central bank who cannot commit, which means it cannot make credible promises about what it will do in the future. Instead, the central bank has the incentive of reoptimizing every period even when it means reneging on past obligations. This behaviour is called discretion and it is generally a second-best outcome with respect to commitment. As a matter of fact, discretionary policy fails to recognize (or is unable to exploit) the importance of people's expectations about future policy as a determinant of current outcomes. If able to credibly precommit, a central bank can steer expectations in a way that furthers its stabilisation goals. The successful management of expectations is generally obtained through the commitment to a rule or a criterion which points out the appropriate course of action at any point in time.

In the case of an inflation target, the central bank, who cannot commit but can control the inflation rate perfectly, optimizes every period a loss function which coincides with society's in order to reach its objectives for inflation and the output gap. Thus, it faces the following optimization problem:

$$V\left(y_{t-1}\right) = E_t \min_{\pi_t} \left\{ \frac{1}{2} \left[\left(\pi_t - \pi^*\right)^2 + \lambda \left(y_t - y^*\right)^2 \right] + \beta V\left(y_t\right) \right\}, \tag{2.7}$$

where the minimization in period t is subject to the constraint imposed by the Phillips curve

$$y_t = \rho y_{t-1} + \alpha \left(\pi_t - E_{t-1}\pi_t\right) + \varepsilon_t, \tag{2.8}$$

where ε_t is an IID supply shock with zero mean and variance σ^2. The short-run Phillips curve describes a situation in which nominal wages are set one period in advance, based on model-consistent expectations, before observing the supply shock at time t. The timing of the model is such that the central bank first observes ε_t and then set π_t.

The value function $V\left(y_{t-1}\right)$, which depends on the only state variable y_{t-1}, can be written as:

$$V\left(y_{t-1}\right) = \gamma_0 + \gamma_1 y_{t-1} + \frac{1}{2}\gamma_2 y_{t-1}^2. \tag{2.9}$$

The first order condition is:

$$\pi_t - \pi^* + \lambda \left(y_t - y^*\right)\alpha + \beta \left(\gamma_1 + \gamma_2 y_t\right)\alpha = 0, \tag{2.10}$$

implying that

$$\begin{array}{rclcl}\pi_t & = & \pi^* + \lambda \alpha y^* - \beta \gamma_1 \alpha - (\lambda + \beta \gamma_2)\, \alpha y_t & = & \widehat{a} - \widehat{b} y_t \\ y_t & = & \rho y_{t-1} + \left(1 - \alpha^2 (\lambda + \beta \gamma_2)\right) \varepsilon_t & = & \rho y_{t-1} + \left(1 - \alpha \widehat{b}\right) \varepsilon_t .\end{array} \tag{2.11}$$

It then follows that $Var[y_t] = \frac{\left(1-\alpha\widehat{b}\right)^2}{1-\rho^2}\sigma^2$ and $Var[\pi_t] = \widehat{b}^2 Var[y_t] = \frac{\widehat{b}^2\left(1-\alpha\widehat{b}\right)^2}{1-\rho^2}\sigma^2$.[7] The price level is not determined, being an $ARIMA(1,1,0)$ process given by

$$p_t = p_{t-1} + \pi_t = p_0 + \sum_{j=1}^{t} \pi_j = p_0 + \widehat{a} t - \widehat{b} \sum_{j=1}^{t} y_j,$$

whose variance is infinite.

Under PLT instead, the monetary authority solves the following optimization problem:

$$V(y_{t-1}) = E_t \min_{p_t} \left\{ \frac{1}{2} \left[(p_t - p_t^*)^2 + \lambda (y_t - y^*)^2 \right] + \beta V(y_t) \right\} \tag{2.12}$$

under the constraint that

$$y_t = \rho y_{t-1} + \alpha (p_t - E_{t-1} p_t) + \varepsilon_t , \tag{2.13}$$

which is the same as before, since $\pi_t - E_{t-1}\pi_t = (p_t - p_{t-1}) - E_{t-1}(p_t - p_{t-1}) = p_t - E_{t-1} p_t$. In order to be consistent with the inflation target, p_t^*, which is the (log) price-level target, must evolve according to the following law of motion: $p_t^* = p_{t-1}^* + \pi^*$.

The first order condition this time is:

$$p_t - p_t^* + \lambda (y_t - y^*)\, \alpha + \beta (\gamma_1 + \gamma_2 y_t)\, \alpha = 0, \tag{2.14}$$

[7] As $\widehat{b}$ is a function of γ_2, neither the variance of inflation nor that of the output gap are actually determined. It is, however, unnecessary to know the value of γ_2 to compare the relative effectiveness of IT and PLT, as it will be shown shortly.

implying that

$$\begin{array}{lllll} p_t & = & p_t^* + \lambda \alpha y^* - \beta \gamma_1 \alpha - (\lambda + \beta \gamma_2) \alpha y_t & = & \widehat{a}_t - \widehat{b} y_t \\ y_t & = & \rho y_{t-1} + \left(1 - \alpha^2 (\lambda + \beta \gamma_2)\right) \varepsilon_t & = & \rho y_{t-1} + \left(1 - \alpha \widehat{b}\right) \varepsilon_t. \end{array}$$

Under PLT $Var[p_t] = \widehat{b}^2 Var[y_t] = \frac{\widehat{b}^2 \left(1-\alpha\widehat{b}\right)^2}{1-\rho^2} \sigma^2$, while the variance of the output gap is the same as in the case of IT. Inflation is given by $\pi_t = p_t - p_{t-1} = \widehat{a}_t - \widehat{b} y_t - \left(\widehat{a}_{t-1} - \widehat{b} y_{t-1}\right) = \pi^* - \widehat{b}(y_t - y_{t-1})$ and its variance is

$$Var[\pi_t] = \widehat{b}^2 Var[y_t - y_{t-1}] = \widehat{b}^2 2(1-\rho) Var[y_t] = \frac{\widehat{b}^2 2(1-\rho)\left(1-\alpha\widehat{b}\right)^2}{1-\rho^2} \sigma^2 = 2\frac{\widehat{b}^2 \left(1-\alpha\widehat{b}\right)^2}{1+\rho} \sigma^2.$$

Two of Svensson's findings are worth stressing:

- first, under PLT the price level is determined and its variance is finite, while, under IT, the price level is indetermined and its variance infinite;
- second, the variance of the output gap is the same as under IT and the variance of inflation is lower if

$$\widehat{b}^2 2(1-\rho) Var[y_t] < \widehat{b}^2 Var[y_t] \Leftrightarrow 2(1-\rho) < 1 \Leftrightarrow \rho > \frac{1}{2}.$$

Svensson reaches the conclusion that if the model displays significant output persistence (ρ is greater than 0.5) then PLT uniformly dominates IT under discretion and it improves the trade-off between inflation and output gap variability. PLT is superior even when judged on the basis of a loss function depending on inflation, not the price level.

The intuition is the following:

i. the higher the output persistence, the closer is the output gap to a random walk;

ii. under IT, inflation is proportional to the output gap while under PLT it is proportional to the change in output gap;

ii. in the first case, inflation resembles a random walk as well, whereas under PLT it remains stationary;

iv. the loss function is accordingly lower under PLT, as the same output gap volatility is matched with a lower standard deviation of inflation.

The possibility that PLT with sufficient output persistence reduces inflation volatility without worsening output gap volatility is often referred to as "free lunch". Furthermore, when the central bank optimizes the loss function in terms of price level, it reduces the so-called stabilisation bias, which is the distortion caused by the central bank when it creates inflation in order to reduce the output gap. This bias would be eliminated if commitment was possible and it characterizes why policy under discretion is sub-optimal. PLT, by partially eliminating this bias, is able to bring about an outcome closer to commitment and optimal policy.

2.6 Vestin: price-level targeting in New Keynesian models

Vestin later tested these findings in a forward-looking New Keynesian framework. The central bank faces essentially the same problem with the difference that instead of a Lucas-type Phillips curve, the constraint is given by the following New Keynesian Phillips curve with exogenous persistence in the cost-push shock:

$$\pi_t = (1-\beta)\pi^* + \beta E_t \pi_{t+1} + \kappa x_t + u_t, \tag{2.15}$$

where

$$u_t = \rho u_{t-1} + \varepsilon_t. \tag{2.16}$$

The IS curve does not appear in the model (and in Svensson's) since it does not impose a constraint in the optimization problem of the central bank. As a matter of fact, Walsh (2010) shows that the first order condition for the interest rate implies that the Lagrangian multiplier in front of the IS curve must be zero at all times (provided that there are no costs associated with changing the interest rate). In general, it is only used in retrieving the interest rate at time t. However, aggregate demand in Vestin's forward-looking model is given by:

$$x_t = -\sigma E_t \sum_{j=0}^{\infty} \left(i_{t+j} - \pi_{t+1+j} - r_t^n \right), \tag{2.17}$$

where r_t^n is the neutral (real) rate of interest.

In this case, 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". However, the IT commitment solution is here taken as a benchmark to evaluate the two alternative policy regimes.

Under discretion, the optimal policy for inflation targeting is given by the following first-order condition: $\pi_t = \pi^* - \frac{\lambda}{\kappa} x_t$. Instead under price level targeting, if there is no exogenous persistence in the cost-push shock, the optimum is reached when $\pi_t = \pi^* - \frac{\lambda}{\kappa}(x_t - x_{t-1})$, which is exactly the solution achieved with IT under commitment (see Appendix A-C). The implication is that Svensson's free lunch can be extended to New Keynesian models and that is always possible to replicate the IT commitment solution by assigning a price level target with a different weight on output stabilisation ($\widetilde{\lambda}$) in the loss function.

In the case of persistence in the cost-push shock (ρ>0), PLT is unable to exactly reproduce the IT commitment solution, which prevents from concluding that PLT is undeniably superior to IT. Vestin found that PLT clearly increases output gap volatility with respect to IT, while it reduces the inflation variability. He constructed the policy frontier by plotting inflation and output gap variance for different weights on output stabilisation λ and found that under discretion, price level targeting dominates inflation targeting.

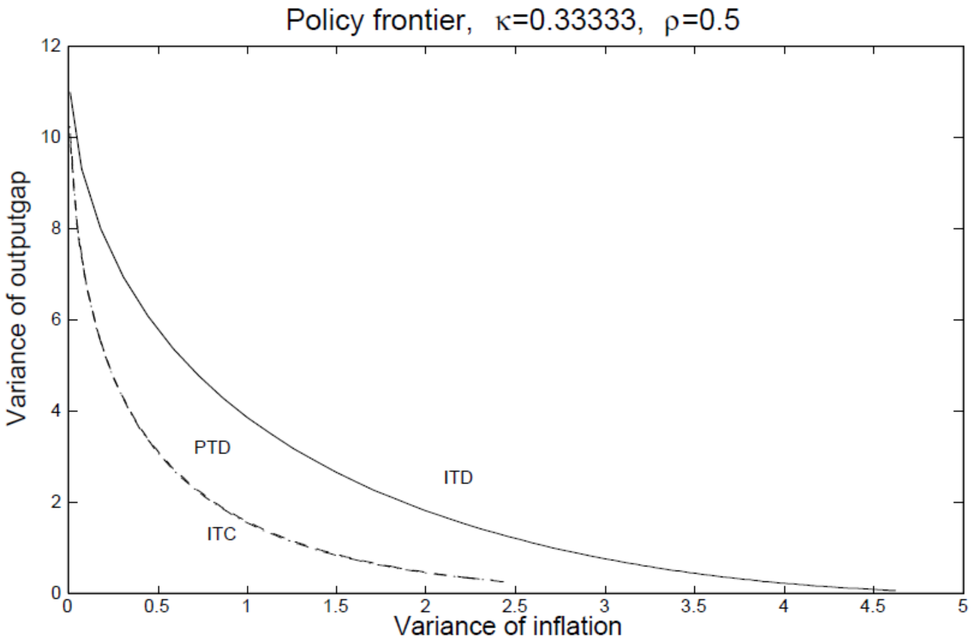

Fig. 2.3: *Policy frontier*

As shown in Figure 2.3, PLT is in general very close to the commitment solution even when persistence in the cost-push shock is non-zero. When persistence approaches 1, there is a more pronounced difference between the two strategies, but PLT is still preferable to IT in the absence of commitment. The reason why PLT is more effective in reducing the trade-off between inflation and output gap variability is precisely that it exhibits history dependence, which allows the central bank not only to affect the output gap but also inflation expectations. In a regime where the central bank targets the price level, a temporary deviation from the objective must be followed by an offsetting deviation in the future, even after the shock has vanished. Firms anticipate this behaviour and adjust their prices, allowing the central bank not to alter aggregate demand as much to bring back inflation on target.

The fact that price level targeting is similar to or even coincides with the commitment solution is not too surprising. Woodford, for example, states that policy under commitment is optimal because it entails some form of 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*”.[8] Thus, history dependence achieves a given degree of moderation of inflationary pressure with less contraction of output.

Cover and Pecorino (2005) also highlight the importance of forward-looking expectations and the advantages of a price level targeting over an inflation targeting regime. The model uses a Lucas aggregate supply curve and an aggregate demand relationship derived from the goods market (IS) and money market (LM) clearing conditions. As opposed to Svensson, the central bank minimizes its loss function before observing the current period supply shock and the aggregate demand side of the economy plays an active role in the determination of the equilibrium. Interestingly, they found that PLT yields a lower variance of output and price level than IT and hence has a stabilising effect through an interest rate channel. In fact, when a disturbance hits the price level, expected inflation moves in the opposite direction, affecting the real interest rate, which causes aggregate demand to shift in a way that stabilizes the economy.

2.7 Price-level targeting and the ZLB

It was around 2003 when concerns about the worldwide decline in the real rate of interest and the possibility of a liquidity trap emerged. Until then Japan was the only country who experienced deflation and the impossibility of lowering further short-term nominal interest rates. Eggertsson and Woodford first posed the question of how monetary policy should prepare for

[8] Woodford M. Interest & Price: Foundation of a Theory of Monetary Policy. Princeton: Princeton University Press, 2003, page 495.

such an occurrence. They first investigated whether quantitative easing could be used as a tool to escape the liquidity trap when the central bank can no longer use nominal rates to bring up inflation. According to the irrelevance proposition, unconventional monetary policy is only effective insofar it manages to change expectations. Through a general-equilibrium analysis of inflation and output determination, they indeed concluded that the expansion of the monetary base through open-market operations cannot be considered an additional tool of monetary policy. Even taking into account portfolio-balance effects, the quantitative significance of the strategy was dubious. The irrelevance proposition seems to capture reality quite effectively, provided that the private sector has a sound understanding of the central bank's commitments regarding future policy. However, open-market operations can be used as a signal of the central bank's commitment, steering private-sector expectations in the right direction.

Although the study was written before the GFC and the debate over the "New Normal", the authors already emphasised that the main trigger for ZLB episodes was the fall in the natural rate of interest. In response to this problem, they briefly considered the idea of raising the inflation target, thereby reducing the ZLB incidence, but concluded that the strategy is far from optimal due to the costs of a higher inflation objective. They identified the IT regime as the problem to begin with, as it does not provide much insurance against the zero lower bound because of its purely forward-looking approach, which neglects past conditions except when they constrain the economy's possible future path (bygones as bygones). The optimal policy should involve some form of history dependence instead.

But how can history dependence alleviate the burden of a liquidity trap? When nominal rates cannot be lowered further, and the zero lower bound is reached, optimal policy should commit to generating future inflation to compensate for the period of deflation. The expectation that nominal interest rates will remain low later when the central bank might otherwise have raised them, should stimulate aggregate demand while the ZLB is binding. Furthermore, the expectation of higher future income should also increase current spending and prices should be less likely to fall as long as future inflation is anticipated. Thus, ZLB distortions should be mitigated with an history-dependent policy.

Eggertsson and Woodford built a New Keynesian model with rational expectations in which the central bank takes decisions in accordance with its objectives (the long-run inflation target is zero), expressed by the same loss function seen previously. In this context, they found that the optimal policy is a history-dependent targeting rule, in which the central bank set the interest rate i_t to match in each period an output gap-adjusted price index ($\widetilde{p}_t$) to the predetermined price level target ($\overline{p}_t$):

$$\widetilde{p}_t = p^*_t. \tag{2.18}$$

Here $\widetilde{p}_t$, the output gap-adjusted price index, is defined as follows

$$\widetilde{p}_t = p_t + \frac{\lambda}{\kappa} x_t, \tag{2.19}$$

while the price-level target evolves period by period according to its shortfall $\Delta_t = \widetilde{p}_t - p^*_t$

$$p^*_{t+1} = p^*_t + \beta^{-1}(1+\kappa\sigma)\Delta_t - \beta^{-1}\Delta_{t-2}. \tag{2.20}$$

If the target is undershot due to the zero bound, the central bank will increase its target for the next period, which will turn into higher inflation expectations, while the bound is binding, and so in a reduction of real interest rates. Once out of the liquidity trap, the margin Δ_t by which the gap-adjusted price level is undershooting the target starts to shrink. Consequently, the target also starts falling until it stabilizes, assuming a constant value which is higher than the one before the ZLB episode.

The rule proposed is not only optimal in response to the threat of a liquidity trap but also in normal times; however, the possibility that people may question the commitment of the central bank to a time-varying price-level target can hinder its implementation. The correct anticipation of the central bank's actions by firms and consumers is key in successfully escaping the "black hole" deflation, so the public should be made aware that the target may not be reached in the short run and that in the meantime a zero-interest rate policy will be executed. To avoid misunderstandings by the public, the central bank can employ a simpler rule, which is a very good approximation of the optimal one,

$$p^* = p_t + \frac{\lambda}{\kappa} x_t. \tag{2.21}$$

The simpler rule differs from the optimal one in the following:

i. it performs slightly worse in a liquidity trap;

ii. it is more easily communicated to the public;

iii. it entails a target for the gap-adjusted price level which is fixed at all times.

In conclusion, Eggertson and Woodford 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, which is particularly useful when the natural rate of interest is as low as currently is. However, it is important that the strategy is well understood by the public and so the central bank has to be very clear in communicating its objectives and targets. For example, if the central bank were to implement the rule suggested by Vestin, i.e. $\pi_t = -\frac{\lambda}{\kappa}(x_t - x_{t-1})$, obtained by taking the difference of 2.21, the outcome would be optimal in normal times but disastrous when the zero bound is binding. The rule, in fact, implies that inflation should be proportional to the negative of the growth rate of the output gap, which implies that the central bank will deflate once outside the liquidity trap. This response is exactly the opposite of what is optimal and delivers an even worse outcome of a strict targeting regime: "it is not enough to replicate the equilibrium behaviour that corresponds to (2.21) at normal times to induce the correct set of expectations when the zero bound is binding."

With the Great Recession, the ZLB stopped being a theoretical concern and became a practical one. 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 framework. Firstly, he recognized that if the ZLB episode associated with the last recession did not happen to be an isolated incidence, then the 2% inflation target would interfere with the Fed stabilization goals.[9] Then, in his work with Orphanides, he analysed how monetary policy could be conducted when the central bank and the private sector possess imperfect knowledge about the real structure of the economy. In fact, it does not seem farfetched that the public may not fully understand central bank policy and that the latter may not be certain about what the natural rate of interest and unemployment are. Orphanides and Williams found that, in this context, a robust optimal policy consists in a difference interest rate rule, which responds to deviations of the level of prices relative to a steadily growing target level, rather than deviations of the inflation rate from a target rate. Through simulation of an FRB/US model, they showed that such a robust policy, which corresponds to a flexible price-level strategy, would have yielded fairly stable inflation during the Great Inflation of the 60s and 70s. The strong anchoring of inflation expectation is the reason why this strategy performs so well, managing to successfully achieve both price stability and high employment.[10] Some years later, Williams (2017) emphasized that a PLT framework, which works well in times of modest uncertainty, is even better suited in

[9]Williams, John C. "Heeding Daedalus: Optimal Inflation and the Zero Lower Bound." Brookings Papers on Economic Activity. Vol. 2009, 2009. https://doi.org/10.1353/eca.0.0074.

[10]Orphanides, Athanasios, and John C Williams. "Robust Monetary Policy with Imperfect Knowledge." Working Paper Series, 2007. http://ssrn.com/abstract_id=989992.

times where the neutral rate of interest is so low. He believes that PLT has all the characteristics of a successful monetary policy regime:

i. adaptability: it appears to be optimal not only in regular circumstances but also in adverse circumstances (potential ZLB episodes);

ii. accessibility: it can be easily understood by the public as it is a "more natural way [..] to think of price stability than an inflation target" and it makes predicting future prices easier, which favours planning-ahead consumer decisions;

iii. accountability: it allows the public to clearly evaluate whether the central bank is compliant with its mandate by looking at whether the price level is close to its required target.

Another work on price-level targeting (Gaspar, Smets, and Vestin 2007) weighs its main benefits and disadvantages. As in previous studies, it finds that the two main gains of PLT are that: i) in an NK RE model, optimal policy demands price-level stability, and ii) price-level stability improves macroeconomic stability when nominal interest rates are at the zero bound. The main difference is that this time the New Keynesian model is a hybrid one, where the Phillips curve displays intrinsic inflation persistence. Once again, the optimal policy under commitment implies a stationary price level and thus is history-dependent. Even in a more complex model with nominal wage stickiness, habit formation and investment adjustment costs,[11] the optimal policy under commitment delivers a stationary price level. Therefore, this strategy appears to be robust to different types of frictions.

Another popular argument made against a price level targeting is that it heavily depends on endogenous expectations, which are formed under unrealistic levels of credibility. Gaspar, Smets and Vestin prove that under adaptive learning, the benefits of PLT can still be reaped in

[11] See Gaspar, Smets and Vestin (2007).

the long run. The speed of convergence to an equilibrium akin to the one obtained under RE with commitment is strongly related to the speed of learning. Furthermore, the costs associated with the transition to a new regime are important but not the deciding factor. Admittedly, if the learning is very slow, the transition process to a PLT regime may be too costly, although the authors believe that this is unlikely.

The other concern is that the history-dependence of the regime would magnify the consequences of past policy mistakes, especially when the central bank is unsure about the structure of the economy. However, the fact that the central bank would need to undo any effects brought forth by its own mistakes is an additional incentive for the central bank to choose a robust strategy: Aoki and Nikolov (2005) and Orphanides and Williams (2011), found that price level targeting is particularly indicated under uncertainty and imperfect knowledge.

Recently, a milder version of price-level targeting has been proposed by Bernanke (2017), who suggests resorting to the implementation of a temporary price-level targeting framework only in periods where conventional policy is constrained by the zero lower bound:[12] the standard practice would be maintained in normal times while a makeup policy would be adopted in periods when the policy rate is limited by the lower bound and inflation is below target. The proposal boils down to allow deviations from the 2% target when short-term interest rates are at or very near zero and to accept that inflation temporarily overshoots its target in order to compensate for past prolonged periods of low inflation. For example, if inflation had been staying at 1.5% for several years, then the central bank should leave the inflation rate at 2.5% for the same number of years, compensating for the missing inflation in the periods when the ZLB prevented monetary policy from providing adequate stimulus. A strong advantage of temporary

[12] In its pure form, the price-level targeting is symmetric; it reacts both if the inflation is above or below the target in order to bring the price level close to its target path. Bernanke's proposal supports the adoption of an asymmetric approach, where only below-target inflation rates need to be offset by above target price dynamics.

price-level targeting is that it has the desirable "history-dependence" feature of the theoretically optimal monetary policy suggested by Woodford. If the public understands and expects the central bank to follow the "lower-for-longer" rate-setting strategy, then the expectations of easier policy should mitigate the fall in output and inflation during the period in which the ZLB is binding, and indeed reduce the frequency with which the ZLB binds at all.

Evans (2012) proposes a straightforward way to communicate the state-contingent price-level targeting to the public in order to avoid credibility issues. Foremost, it is important to convey that such a policy would only be enforced whenever the central bank is missing both components of its dual mandate due to a liquidity trap. A credible announcement is fundamental to steer the right endogenous expectations. Secondly, the central bank should appropriately choose the initial date of the index-path and the slope of the path. After that, the central bank should stress that the targeted path for the level of prices should be reached in a reasonable amount of time and should keep the public updated on the progress made to reach the target. Finally, the central bank should clearly state the terms for the exit of the PLT policy. It is not advised to leave the strategy as soon as the target is reached, as it is important that the price-level path is reached with confidence.

A strategy akin to temporary PLT is average inflation targeting, where the inflation target is defined as a medium-term average rather than as a rate. This adjustment to inflation targeting has been adopted by the Reserve Bank of Australia in the early 1990s. The outcomes of the Australian monetary policy have been very positive since then, with an average inflation rate of 2.7% (close to the midpoint of the target range of 2-3%)[13] in the last two decades and no recession in the last twenty-five years (Mishkin 2017).

In conclusion, a large strand of literature identifies price-level targeting as the optimal pol-

[13] The Reserve Bank of Australia, in defining its target, state that “the appropriate target for monetary policy is to achieve an inflation rate of 2-3%, on average, over the cycle”.

icy at all times, but particularly when a liquidity trap threatens the accommodation needed to stabilise the economy. The main drawbacks that challenge the implementation of this policy are:

1. the unrealistic assumptions behind the expectations channel of monetary policy transmission: the private sector bases its economic decisions on expectations about future economic conditions and can fully understand the monetary policy strategy and its implementation. Moreover, under RE, the private sector catches on immediately to any regime change and thus transition costs and adaptive learning are ignored while a switch in regime would most likely entail considerable education and explanation by policymakers;

2. the commitment of the central bank to the new target must be credible for it to succeed;

3. PLT is a "two-edged sword" in the sense that the central bank should tighten monetary policy when a positive supply shock drives up inflation. This tightening would come at a time when both employment and output are already depressed and so offsetting positive deviations from the target is likely to be costly.

2.8 Average inflation targeting

In 2005, Nessén and Vestin proposed a strategy, *average* inflation targeting, which lies in between price-level targeting and inflation targeting, in the sense that it exhibits some degree of history dependence and it is sufficiently similar to the current policy framework. They found that such a strategy may outperform both price-level targeting and one-period inflation targeting in a model where price setters' behaviour is relatively backward-looking.

Nessén and Vestin (2005) 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 the average of inflation, measured over a given horizon, on target. This implies that AIT exhibits gradualism: to keep the average inflation close to target (π^*), if in the previous period inflation undershot π^*, inflation in the current period must be kept above target. Thus, AIT display history dependence, even if in a lower degree with respect to PLT.

Vestin (2000) proved how in a forward-looking model PLT is superior to inflation targeting (IT). Nessén and Vestin (2005) extend this model (see Section 2.6) to include average inflation targeting and see how it measures up to the other two regimes. In this case, the central bank is tasked by society with minimising the following loss:

$$L_t^{ITj} = \frac{1}{2}\,[\left(\bar{\pi}_{j,t} - \pi^*\right)^2 + \widetilde{\lambda} x_t^2], \tag{2.22}$$

where the target π^* is zero for simplicity and where $\bar{\pi}_{j,t}$ is the j-period average inflation rate, defined as:

$$\bar{\pi}_{j,t} = \frac{1}{j}\sum_{s=0}^{j-1} \pi_{t-s} = \frac{1}{j}(p_t - p_{t-j}). \tag{2.23}$$

The performance of the three strategies is measured according to the true loss function, i.e. the society per-period loss function, which is rewritten as:

$$L_t^* = \frac{1}{2}\,[(\pi_t - \pi^*)^2 + \lambda^* x_t^2]. \tag{2.24}$$

As proved in the past, in this set-up, the price level under PLT is stationary and there is an inverse relationship between the price level and the output gap. Furthermore, the policy responses are persistent even if the shock is only temporary, as opposed to inflation targeting. Policy responses of average inflation targeting, where the average rage is taken over two periods, are also persistent, although to a lower degree (see Appendix D). By looking at the policy frontier (Figure 2.4), it is clear that in a forward-looking model, PLT is superior to both inflation targeting and average inflation targeting, while in turn, AIT dominates IT under discretion.

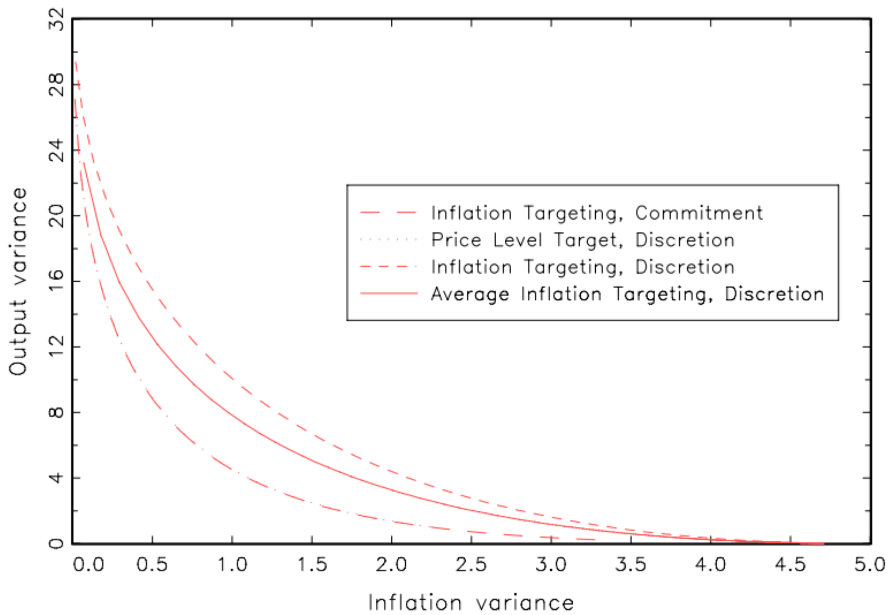

Fig. 2.4: *Variance Frontiers in Simple New-Keynesian Model (Nessén and Vestin 2005)*

Nessén and Vestin also assessed the relative performance of these strategies in a hybrid model, where firms set their prices on the basis of new and past information. The Phillips curve and its associated shock then become:

$$\begin{aligned} \pi_t &= (1-\omega)E_t\pi_{t+1} + \omega\pi_{t-1} + \kappa x_t + \eta_t \\ \eta_t &= \gamma_1\varepsilon_t + \gamma_2\varepsilon_{t-1} \end{aligned} \tag{2.25}$$

where ω represents the fraction of firms which follow a rule-of-thumb behaviour in setting prices and thus base their decision on the basis of past prices. The shock η_t is a shock to the pricing power of firms, which reflects the fact that some price setters respond to old information. In the hybrid model, society's loss function, and thus the criterion to evaluate strategies' performance, is given by:

$$L_t{}^{*} = (\pi_t - \pi^{*})^2 + \lambda_1 x_t^2 + \lambda_2 \Delta\pi_t^2 + \lambda_3 x_{t-1}^2 + \lambda_4 x_t^2 + \Delta\pi_t x_{t-1}. \tag{2.26}$$

It appears that the relative performance of the different policy frameworks changes with ω, the degree of inertia in the Phillips curve. Indeed for $0 \leq \omega \leq 0.43$, price-level targeting is still superior to inflation targeting and average inflation targeting, while for $0.43 \leq \omega \leq 0.68$ average inflation targeting (under different specification of j) outperforms the other two regimes. Furthermore, the authors found that, with a high degree of inertia, the AIT expected loss is lower for shorter horizons of the average of inflation.

In the next chapter, I will try to assess the effectiveness of alternative monetary policy strategies in overcoming the ELB.

Chapter 3

Simulation evidence on alternative monetary strategies

3.1 Model and simulation design

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. Among the strategies discussed, I have chosen to assess the effectiveness of different monetary policy frameworks under discretionary policy: a higher inflation target against the adoption of a price-level targeting strategy. I have also considered the performance of an average inflation targeting (AIT for short) framework, following the proposal put forth by Néssen and Vestin, which represents a ”middle-way” between IT and

PLT, as it introduces some degree of history-dependence through the time length used in calculating the average inflation. The history dependence of this strategy is significantly more limited with respect to PLT since the latter is roughly equivalent to taking an infinite average of inflation. I evaluated 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, the current inflation targeting regime is used as a benchmark to evaluate the different proposals, while IT under commitment is used as a reference to the best outcome that can be achieved.

As seen in the previous chapter, the current literature finds that under discretion price level targeting is superior to an inflation targeting regime in the following cases:

1. in a backward-looking New Classical model with significant output persistence (ρ>0);
2. in a forward-looking New Keynesian model, in particular, when there is no persistence in the cost-push shock, as in that case PLT replicates the equilibrium achieved by IT under commitment.

In this section, I will try and assess whether the superiority of PLT over the current IT regime holds in a new Keynesian model in which endogenous persistence is present in both the Phillips and IS curve. I also consider average inflation targeting, as it may be possible that it outperforms PLT since there are some backward-looking components in the model. Additionally, I will assess the effectiveness of an IT strategy with a higher inflation objective, which may be particularly appropriate to deal with the increasing threat of ZLB episodes.

For the evaluation of each strategy, I use a New Keynesian model in which households optimize utility (which generates the dynamic 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 performance of each strategy will be evaluated on the basis of two criteria:

1. the minimisation of a linear combination of the variability of inflation and the output gap, which represents society's loss function. In some cases I will include in the loss function the volatility of the monetary policy interest rate as well;

2. the ability to reduce the incidence of the zero lower bound.

The two different criteria approximately represent the performance of each regime in either normal times or when monetary policy is constrained by the zero lower bound. In the first case, society's expected loss function is the impartial yardstick chosen to compare the performance of all the frameworks in normal times. In the second case, the incidence of the ZLB is measured with an approach akin to the one used by Schimmt-Grohé and Uribe (2011), where the relevance of the ZLB is estimated taking into account how many times the constraint is violated.

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

$$\begin{aligned} \pi_t &= \psi E_t \pi_{t+1} + (1-\psi)\,\pi_{t-1} + \kappa x_t + u_t \\ x_t &= \chi E_t x_{t+1} + (1-\chi)\,x_{t-1} - \sigma\,(i_t - E_t \pi_{t+1} - r^n) \end{aligned} \tag{3.1}$$

The first equation is the Phillips curve, which characterises the behaviour of inflation π_t, while the second equation is the dynamic 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 (ψ=0.72), while consumers optimise their utility[1] mainly on the basis of their past decisions (χ =0.09). The annual natural rate of interest r^n is adjusted to recent estimates and is equal to 1% in accordance with Kiley (2015) and Del Negro (2017). The cost-push shock u_t in the Phillips curve is an AR process of order one, where the shock persistence parameter ρ is equal to 0.75.

A desirable monetary policy strategy achieves a low expected value of the discounted sum of the current and future losses for society due to economic volatility, where the loss in each period is 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:

$$\min_{x_t} E_t\,(1-\beta)\sum_{i=0}^{\infty}\beta^i L_{t+i} \tag{3.2}$$

where L_t depends on which regime 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:

$$L_t^{IT} \;=\; \frac{1}{2}\,[(\pi_t-\pi^*)^2+\lambda x_t^2] \tag{3.3}$$

$$L_t^{PLT} \;=\frac{1}{2}[(p_t-p^*)^2+\widetilde{\lambda} x_t^2] \tag{3.4}$$

$$L_t^{AIT} \;=\; \frac{1}{2}\,[\left(\bar{\pi}_{j,t}-\pi^*\right)^2+\bar{\lambda} x_t^2] \tag{3.5}$$

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

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

$$\bar{\pi}_{j,t} = \frac{1}{j}\sum_{s=0}^{j-1}\pi_{t-s} = \frac{1}{j}(p_t - p_{t-j}) \tag{3.6}$$

The central bank is concerned with stabilising inflation and output: 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, and the difference between the expected loss given by 3.3 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 3.3 and more specifically:

$$L_t^{Society} = Var(\pi_t) + \lambda Var(x_t) \tag{3.7}$$

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

The comparison between the alternative monetary regimes is done by means of stochastic simulations[2]: I generate 1000 replications for 200 periods (i.e. 40 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, I calculate the variability of endogenous variables and the policy (or efficiency) frontier for all strategies.

[2]Stochastic simulations are done with the software Dynare and the codes for each strategy in the baseline case can be found in Appendix E.

3.2 Results: the baseline case

The benchmark is given by inflation targeting with an objective of inflation of 2%, under the assumption that the central bank is unable to commit. The case of IT under commitment is considered as a reference to the best outcome that can be achieved.

3.2.1 Commitment vs. Discretion

Commitment and discretion generally differ because in the first case the behaviour of the central bank is ”predictable” and is able to better anchor inflation expectations. A discretionary policy, although characterised by greater flexibility, always underperforms a policy under commitment, because it cannot steer expectations so efficiently. Policy commitment, however, is difficult to implement due to the so-called time inconsistency problem, which ”arises whenever the effectiveness of a policy today depends on the credibility of the commitment to implement that policy in the future.”[3] Monetary authorities around the world try and achieve a solution closer to commitment by enhancing their credibility through transparency (setting a numerical inflation objective and publishing the progress made in realizing it) while also retaining a certain degree of flexibility. In practice, central bank behaviour displays features of both commitment and discretion, but since full or perfect credibility is unlikely to occur in the real world, I'll assume that central banks are only able to carry out discretionary policy.

Below, the performance of inflation targeting with a 2% inflation objective is displayed under both commitment and discretion to point out how much of a difference credibility can make.

If full credibility were possible, inflation and interest volatility could be, respectively, almost one-sixth, and one-half as volatile as under discretion. Though a commitment policy seems to be somewhat less effective in stabilising the output gap, it nonetheless exhibits a better variance

[3] Cecchetti (2018) in the article ”Time Consistency: A Primer” posted in his blog

Tab. 3.1: **IT: commitment vs. discretion**

	Commitment	Discretion
Variance of inflation	0.0248	0.1428
Variance of output gap	0.9035	0.5658
Variance of interest rate	0.3442	0.8047

trade-off between inflation and the output gap: the society's expected loss is equal to 0.0682 in the case of commitment and 0.1699 in the case of discretion.

Commitment is also effective when interest rates are low and the chances of hitting the ZLB are high. Indeed, it is one of the most successful strategies in this respect, with a probability of ZLB incidence of only 10.04%, as shown below.

3.2.2 Comparison of alternative monetary policy frameworks

The main purpose of this research, however, is the comparison between the different strategies proposed to mitigate the problem of the zero lower bound: (i) the current IT regime; (ii) IT with a higher inflation objective; (iii) PLT; (iv) an average inflation targeting framework. 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 significantly unstable should not be adopted even if it could eliminate the threat of a liquidity trap. This is why many economists are not in favour of an increase in the inflation target. Unfortunately, the 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.

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 each simulation 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.

Tab. 3.2: **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

The efficiency of each strategy in achieving policy objectives is measured by the loss function in equation 3.7, which represents society's preferences. Model simulations generate the following ranking - from best to worst - among strategies: 1) IT under commitment, 2) PLT under discretion, 3) AIT (average taken over 3 years), 4) AIT (average taken over 2 years), and 5) IT (under discretion), regardless of whether the inflation target is 2% or 4%. As mentioned before, although model simulations generate this ordering and an apparent tie between IT strategies with different inflation objectives, it should be stressed that a higher inflation target

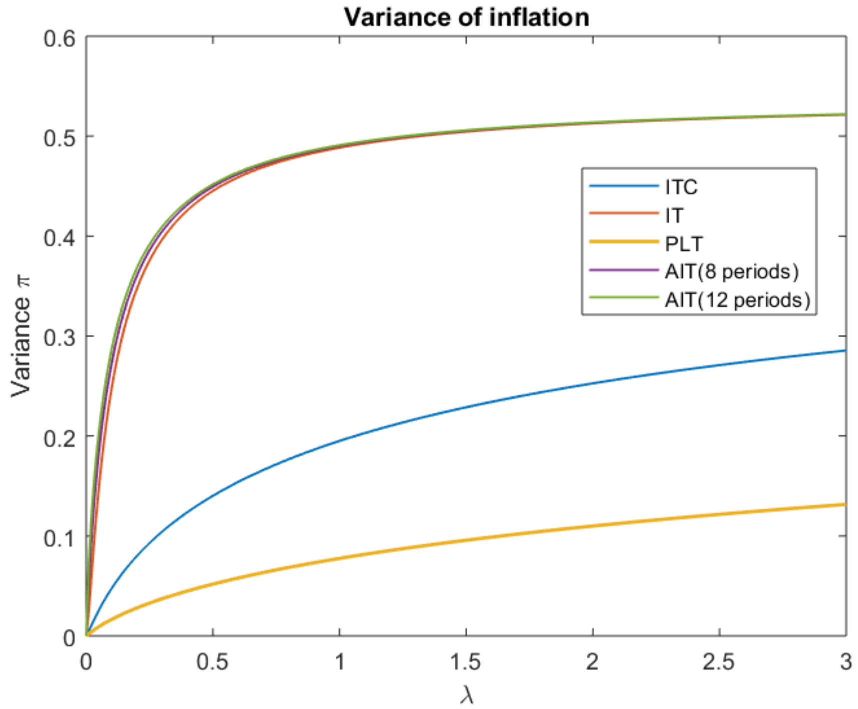

Fig. 3.1: **Variance of inflation under alternative policy frameworks**

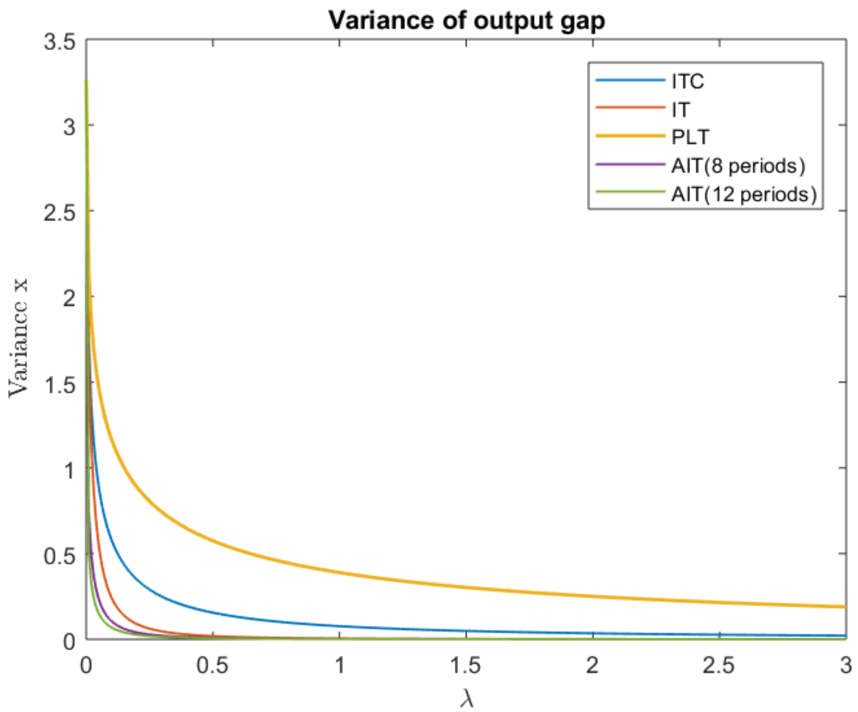

Fig. 3.2: **Variance of output gap under alternative policy frameworks**

is expected to produce more instability and costs that are not measured by the loss function[4] 3.7 and thus IT with a higher π^* can be judged to 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 (λ=0.048), and the ranking may be quite different for different values of λ. Also, interest rate variability is not accounted for in 3.7, since supposedly society is only concerned with stable inflation and output gap.

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 3.1 and 3.2 show how 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. IT performance 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 3.4 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.

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

[4] See Section 2.4

3.3 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 under discretion, but it is the better alternative when the central bank acts under discretion. When the central bank is able to commit, PLT comes very close to replicate 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.

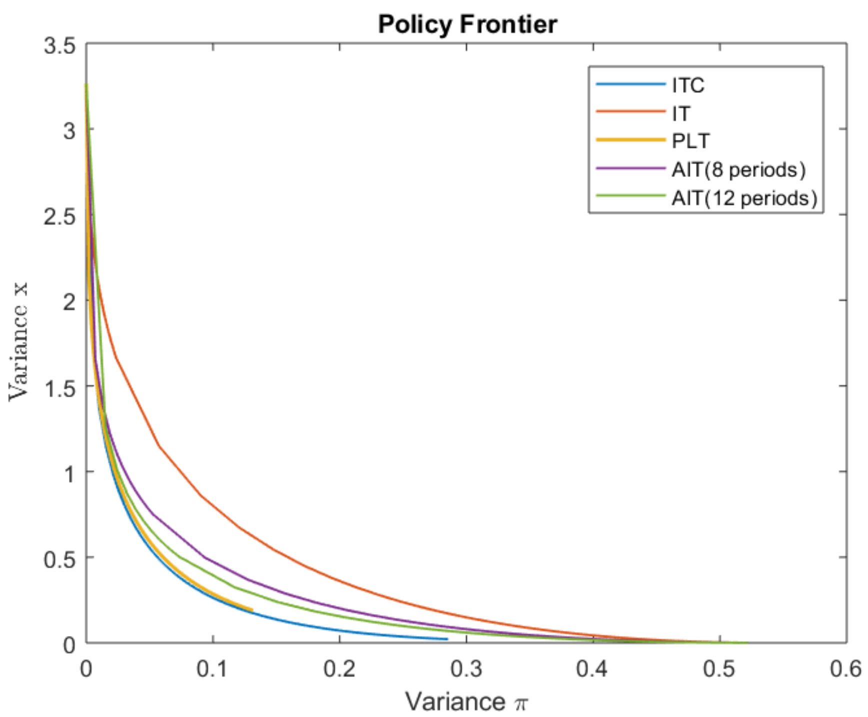

Fig. 3.3: **Policy frontier under alternative policy frameworks**

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 at least once. 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.

Tab. 3.3: **Performance at the ZLB of alternative monetary policy frameworks**

	Commitment			Discretion		
ZLB	**IT(2%)**	**IT(2%)**	**PLT**	**IT(4%)**	**AIT(8 p.)**	**AIT(12 p.)**
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 quarters 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 in the range of 8-11 quarters.

It should be stressed out, however, that simulation results probably overestimate the power 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 3.1 to π^* and accordingly biases simulation results in favour of strategies that raise the inflation target.[5]

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

[5] 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.

IS curve on the variance of the interest rate. But why is the output gap so volatile? In Chapter 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 decision 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 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.

3.3 Sensitivity analysis

In this section, I assess the sensitivity of the results, *ceteribus paribus*, to some of the more relevant parameters of the model, namely:

1. the degree of inertia in both the Phillips curve (ψ) and the IS curve (χ);
2. the slope of the Phillips curve (κ);
3. the persistence of the cost-push shock (ρ);
4. the intertemporal elasticity of substitution (σ) in the IS curve;
5. 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-looking behaviour increases. In the second one, I expect the inflation and output gap variance trade-off to worsen with a flatter Phillips curve. 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 ($\chi \geq 0.70$), 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 policy frameworks. The ranking of the strategies remains unaltered with respect

[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 3.4, is the same as in the baseline, ranking second in place after commitment.

to the baseline case.

Persistence of 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 performance at the ZLB worsen for lower values of the intertemporal elasticity of substitution. Across strategies, 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.

3.4 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 output gap does not necessarily imply financial stability, and financial stability could 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:

$$L_t^{Society} = \frac{1}{2}\left[(\pi_t - \pi^*)^2 + \lambda_x x_t^2 + \lambda_i (i_t - i^*)^2\right] \tag{3.8}$$

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 3.3-3.5, with the addition of the last term of 3.8. 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 sur-

Tab. 3.4: **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

prising: 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.

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 it is not particularly effective neither in normal times nor 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.

3.5 Why is PLT so inefficient at the ZLB

In the baseline case, I have established that PLT is the best strategy in normal times, as it manages to stabilize the economy mitigating output and inflation fluctuations, but it is not as good at keeping interest rates far from the ZLB constraint. As mentioned in Section 3.2.2, the intuition behind its poor performance at the ZLB is that to operate effectively PLT requires a mostly forward-looking IS and Phillips curve. The Phillips curve in the model is not purely forward-looking but there is a sufficient weight on future inflation expectations (ψ=0.72) to suggest that the problem does not lie with expectations in the supply side of the economy. On the other hand, the IS curve is mostly backward-looking, with weight on future expectations of the output gap as low as 0.09. I think that this may be the key in explaining why PLT performs so badly at the ZLB when so many other researches advocate for such a regime in order to better cope with a low interest rate environment. The sensitivity analysis seems to confirm this hypothesis. Changing the degree of inertia in the IS curve leads to a significant reduction of the frequency and severity of ZLB episodes under PLT. What is striking is that for $\chi \geq 0.70$ (greater weight on forward-looking behaviour), PLT is the most effective discretionary strategy under the two criteria established.

By changing the parameter χ in the IS curve, the volatility of inflation and output gap does not change, so the ranking given by the expected loss of society is the same as in the baseline case. The only change is in the volatility of interest rate, which is much lower for all policy strategies. In the case of IT under discretion and of the two different specifications of AIT, interest rate variability is halved, while in the case of PLT interest rate variability is one-tenth of the one associated with backward-looking expectations in the IS curve. Finally, IT under commitment improves very slightly but insignificantly with respect to the others.

The lower variability in the nominal interest rate suggests that the performance at the ZLB is improved for each strategy. By looking at the frequency of the ZLB, it is easy to see that this is indeed the case: all frameworks have a lower probability of incurring a liquidity trap. However, the ranking of the effectiveness of the regimes at the ZLB is different. Under discretionary policy, PLT ranks highest with a ZLB incidence of 0.56%, outperforming even inflation targeting with a 4% target, which trails not too far behind (1.26%). Three-year AIT and two-year AIT follow and in last place stands the current IT framework.

This finding is robust to the different specification of the loss function analysed in Section 3.5. Indeed, increasing the weight on forward-looking expectations makes PLT the most successful strategy. For a value of $\chi \approx 0.70$, the PLT expected loss amount to 0.08 and is second only to commitment. Furthermore, the ZLB incidence falls directly to zero.

Finally, Néssen and Vestin (2005) found that, when backward-looking elements are included in the model, the performance of PLT deteriorates and AIT strategies become much more effective. In the case they analysed, it was only the Phillips curve that displayed endogenous persistence and the performance at the ZLB was not something they analysed. However, it seems that their results extend also to a model where the IS curve displays endogenous persistence and where the ZLB constraint is taken into account. For low values of χ, the performance of PLT is not particularly good at reducing the incidence of the ZLB and it is outperformed by AIT, while for higher values (e.g. χ=1) PLT is the most effective strategy.

3.6 Limitations

The model here used to evaluate the effectiveness of alternative monetary policy strategies is extremely simplified. It describes the working of the economy by means of only three simple equations; a lot of mechanisms and interactions are left out. The most relevant simplifications are those related to the monetary policy transmission channels, namely:

i. the model assumes that there is no foreign sector and that the economy is closed. Accordingly, there is no exchange rate and no exchange rate transmission channel;

ii. there is no capital and hence no cost-of-capital transmission channel. As investment is the most volatile GDP component and the one most sensitive to interest rate changes, this is not a negligible drawback;

iii. there are no banks and no bank lending channel: for an economy like the euro area where bank-based finance is by far the main source of financing for households and firms, this is not a harmless simplification.

This simple New-Keynesian model is basically able to capture only the intertemporal substitution in consumption, e.g. the delaying of consumption due to interest rate hikes or the frontloading of household spending in response to a monetary policy loosening. Other simplifications are made in the model (no public sector, no involuntary unemployment, the policy interest rate as the only financial variable), but for my research question, the most significant ones have to do with the monetary policy transmission channels.

Last but not least, in evaluating the effectiveness of the different strategies, the model does not capture credibility issues, or the learning process that is invariably linked to the adoption of either a new inflation target or a new monetary policy strategy: the model assesses the performance of alternative monetary policy frameworks as if they had been in place for a long period of time and the central bank were always fully effective in anchoring expectations.

Conclusions

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 proved to be very successful since its introduction in the 1990s, when inflation was high and volatile, nowadays it is facing a wave of criticism, which brings into question, in particular, its ability to fight severe recessions. In contrast to the early 1990s, the problem is that now inflation is too low, as many countries are undershooting, rather than overshooting, their targets. This is a direct result of the Great Recession, when monetary policy was constrained by the zero lower bound and inflation was consistently below target.

The steady decline in the natural rate of interest coupled with evidence of a flattening of the Phillips curve has made the conduct of monetary policy more complex. Both developments pre-date the global financial crisis but contributed to the lasting effects of the past recession. The decline in the neutral rate of interest increases the probability of entering a liquidity trap, as it narrows the room for manoeuver of standard monetary policies to fight recessions. The flattening of the Phillips curve makes monetary policy more difficult, as it weakens the transmission of monetary policy impulses, making inflation and output more volatile. These two phenomena seem to be persistent and it is unlikely that they will disappear in the near future.

These changes in the economic landscape sparked a new strand of research, which focuses on whether inflation targeting is still a viable solution for ensuring price stability or whether there are more effective alternatives. Some economists and policymakers claim that inflation targeting can be rescued if a higher inflation is adopted in light of the increased incidence of zero lower bound episodes; others think that switching to a new regime, such as price-level targeting is likely to yield superior outcomes. This dissertation evaluates the performance of different monetary policy frameworks with respect to the actual 2% inflation targeting regime, taking into account the fall in the natural interest rate and the constraint posed by the ZLB. The strategies analysed include a higher inflation objective (4% rather than 2% as currently adopted in most advanced economies), a price-level targeting regime and an ”intermediate” regime between the two, i.e. average inflation targeting.

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: a higher inflation objective (4%) and the two specifications of the j-period average inflation targeting ($j = 8$ and $j = 12$) substantially reduce the probability of hitting the ZLB, which falls to 8.16% in the former case and to 10.97% or 9.11% in the latter. Surprisingly, the worse performance in terms of reducing the probability of hitting the ZLB is achieved by price-level targeting, with a ZLB incidence of 22.93%. The apparent superiority of a higher inflation objective is largely due to the inability of the three-equation New Keynesian model to account for the costs of raising the inflation target: it is not unlikely that a risk-averse policymaker might prefer a slightly higher probability of hitting the ZLB rather than bearing the unknown credibility costs of reneging its commitment to a 2% inflation objective.

With endogenous persistence in the model, in normal times PLT is still superior to any other strategy analysed, but its performance at the ZLB is far from 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.

A limitation of the quantitative analysis presented in this thesis is that all the 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 and the central bank were in all circumstances fully effective in anchoring expectations. Additional research is clearly needed to address in a more comprehensive and reliable way how to design effectively the ”New Normal” of monetary policy.

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 bear the potentially very significant costs of a higher inflation objective. Finally, it is the only alternative among the ones analysed which has been actually adopted by at least a central bank (Bank of Australia).

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Appendices

Appendix A

Inflation targeting under commitment

In a commitment regime, the central bank can make credible promises about what it will do in the future. The main advantage of such a regime is that by promising to take certain actions in the future, the central bank can influence the public's expectations about future inflation and can raise the effectiveness of interest rate management. Inflation targeting under commitment is, therefore, the best outcome that a central bank minimising a loss function with inflation and output gap variability as arguments can achieve.

The central bank's objective is to choose i_{t+1}, π_{t+i} and x_{t+i} to solve the following problem:

$$\min_{\pi_t, x_t, i_t} E_t \sum_{i=0}^{\infty} \frac{\beta^i}{2} \left(\pi_{t+i}^2 + \lambda x_{t+i}^2\right)$$

$$s.t. \begin{cases} E_t \pi_{t+i} & = & E_t \left\{\beta \pi_{t+1+i} + \kappa x_{t+i} + u_{t+i}\right\} \\ E_t x_{t+i} & = & E_t \left\{x_{t+1+i} - \sigma \left(i_{t+i} - \pi_{t+1+i} - r_{t+i}^n\right)\right\}. \end{cases}$$

The First Order Condition (FOC) for i_{t+i} takes the form $\sigma^{-1} E_t \theta_{t+i} = 0$, where θ_{t+i} is the Lagrange multiplier associated with the IS curve. The FOC states that $E_t \theta_{t+i} = 0$ for all i's, implying that the constraint does not bind at all. The IS curve can be dropped from the optimisation problem and the output gap used as the central bank's policy instrument. Given the central bank's optimal choices for the output gap and inflation, the IS curve will simply determine the setting for i_{t+i} necessary to achieve the desired value of x_{t+i}.

The optimisation problem can therefore be written as

$$\min_{x_t} E_t \sum_{i=0}^{\infty} \left\{ \frac{\beta^i}{2} \left(\pi_{t+i}^2 + \lambda x_{t+i}^2 \right) + \phi_{t+i} \left(\pi_{t+i} - \beta \pi_{t+1+i} - \kappa x_{t+i} - u_{t+i} \right) \right\} \tag{A.1}$$

and the FOCs are:

$$\begin{array}{lcll} \pi_t + \phi_t & = & 0 & \\ E_t \left(\pi_{t+i} + \phi_{t+i} - \phi_{t-1+i} \right) & = & 0 & i > 0 \\ E_t \left(\lambda x_{t+i} - \kappa \phi_{t+i} \right) & = & 0 & i \geq 0. \end{array} \tag{A.2}$$

The first two equations reveal that the optimal commitment policy is time-inconsistent, because the central bank promises to do tomorrow something different from what is optimal today: a central bank re-optimising every period would, therefore, find convenient to renege on past promises and always set $\pi_t + \phi_t = 0$. A way out of this conundrum is to adopt the *timeless perspective* approach to precommitment, which means to define the optimal commitment policy as the one that implements in all periods the final two conditions in (A.2). Combining these two FOCs reveals that inflation and the output gap must satisfy

$$\pi_{t+i} = -\frac{\lambda}{\kappa} \left(x_{t+i} - x_{t-1+i} \right). \tag{A.3}$$

Substituting (A.3) in the Phillips curve gives the following equation for the output gap:

$$-\frac{\lambda}{\kappa} \left(x_t - x_{t-1} \right) = -\frac{\beta \lambda}{\kappa} \left(E_t x_{t+1} - x_t \right) + \kappa x_t + u_t$$

that can be rearranged to become a 2nd order difference equation in x_t:

$$x_{t+1} - \frac{\kappa^2 + \lambda (1 + \beta)}{\beta \lambda} x_t + \frac{1}{\beta} x_{t-1} = \frac{\kappa}{\beta \lambda} u_t. \tag{A.4}$$

The two roots of (A.4), z_1 and z_2, are found by solving

$$z^2 - \frac{\kappa^2 + \lambda (1+\beta)}{\beta\lambda} z + \frac{1}{\beta} = 0 \tag{A.5}$$

and are given by

$$z_1, z_2 = \frac{\frac{\kappa^2+\lambda(1+\beta)}{\beta\lambda} \pm \sqrt{\left(\frac{\kappa^2+\lambda(1+\beta)}{\beta\lambda}\right)^2 - \frac{4}{\beta}}}{2} = \frac{1 \pm \sqrt{1 - \frac{4\beta\lambda^2}{\left(\kappa^2+\lambda(1+\beta)\right)^2}}}{2\frac{\beta\lambda}{\kappa^2+\lambda(1+\beta)}}$$

where $\delta \equiv z_1 < 1$ and $z_2 = \frac{1}{\beta z_1} = \frac{1}{\beta\delta} > 1$. Equation (A.4) becomes

$$\begin{aligned}
(1-\delta L)\left(1 - \tfrac{1}{\beta\delta} L\right) x_{t+1} &= \tfrac{\kappa}{\beta\lambda} u_t \\
(1-\delta L)(1-\beta\delta F)\left(-\tfrac{1}{\beta\delta} L\right) x_{t+1} &= \tfrac{\kappa}{\beta\lambda} u_t \\
(1-\delta L)x_t &= (-\beta\delta)\tfrac{1}{1-\beta\delta F}\tfrac{\kappa}{\beta\lambda} u_t \\
(1-\delta L)x_t &= -\tfrac{\delta\kappa}{\lambda}\tfrac{1}{1-\beta\delta\rho} u_t
\end{aligned} \tag{A.6}$$

where L and $F \equiv L^{-1}$ are, respectively, the backward and forward operator. More transparently, the last equation can be written as:

$$x_t = \delta x_{t-1} - \frac{\delta\kappa}{\lambda}\frac{1}{1-\beta\delta\rho} u_t. \tag{A.7}$$

Substituting (A.7) into (A.3), allows to recover the law of motion of inflation, which is equal to:

$$\begin{aligned}
\pi_t &= -\tfrac{\lambda}{\kappa}(x_t - x_{t-1}) \\
&= -\tfrac{\lambda}{\kappa}\left(-\tfrac{\delta\kappa}{\lambda}\tfrac{1}{1-\beta\delta\rho}\tfrac{1}{1-\delta L} u_t + -\tfrac{\delta\kappa}{\lambda}\tfrac{1}{1-\beta\delta\rho}\tfrac{1}{1-\delta L} u_{t-1}\right) \\
&= \tfrac{1}{1-\delta L}\tfrac{\delta}{1-\beta\delta\rho}(u_t - u_{t-1})
\end{aligned}$$

or, more transparently,

$$\pi_t = \delta\pi_{t-1} + \frac{\delta}{1-\beta\delta\rho}(u_t - u_{t-1}). \tag{A.8}$$

By integrating both sides of the last equation, (A.8) can also be written in terms of the price level as

$$p_t = \delta p_{t-1} + \frac{\delta}{1 - \beta\delta\rho} u_t. \tag{A.9}$$

Appendix B

Inflation targeting under discretion

If the central bank does not possess a commitment technology and is forced to operate under discretion, the optimal policy is found by solving the following minimisation problem:

$$\begin{gathered} V_t\left(u_t\right)=E_t\left[\min_{x_t} \tfrac{1}{2}\left(\pi_t^2+\lambda x_t^2\right)+\beta V_{t+1}\left(u_{t+1}\right)\right] \\ s.t.\ \pi_t=\beta E_t \pi_{t+1}+\kappa x_t+u_t \end{gathered} \tag{B.1}$$

with u_t being an AR(1) process with autocorrelation coefficient ρ. Being u_t the only state variable, the solution for π_t is of the form:

$$\pi_t=a u_t \tag{B.2}$$

and the Phillips curve can be alternatively written as

$$\pi_t=\beta E_t a u_{t+1}+\kappa x_t+u_t=\kappa x_t+(1+\beta a \rho) u_t . \tag{B.3}$$

The first order condition is:

$$0=E_t\left(\pi_t \frac{\partial \pi_t}{\partial x_t}+\lambda x_t\right)=\pi_t \kappa+\lambda x_t$$

implying the following relationship between inflation and the output gap:

$$x_t = -\frac{\kappa}{\lambda}\pi_t. \tag{B.4}$$

Substituting (B.4) into (B.3) gives

$$\pi_t = \kappa\left(-\frac{\kappa}{\lambda}\pi_t\right) + (1+\beta a\rho)\,u_t$$

which implies

$$\pi_t = \frac{\lambda\,(1+\beta a\rho)}{\kappa^2+\lambda}u_t. \tag{B.5}$$

Equating the right-hand side of (B.2) and (B.5), one obtains

$$a = \frac{\lambda\,(1+\beta a\rho)}{\kappa^2+\lambda} = \frac{\lambda}{\kappa^2+\lambda\,(1-\beta\rho)}.$$

The equilibrium solutions for inflation and the output gap are therefore:

$$\left\{\begin{array}{lllll} \pi_t & = & \frac{\lambda}{\kappa^2+\lambda(1-\beta\rho)}u_t & & \\ x_t & = & -\frac{\kappa}{\lambda}\frac{\lambda}{\kappa^2+\lambda(1-\beta\rho)}u_t & = & -\frac{\kappa}{\kappa^2+\lambda(1-\beta\rho)}u_t. \end{array}\right. \tag{B.6}$$

Appendix C

Price-level targeting under discretion

Assuming that $\pi^* = x^* = p^* = 0$, optimal price-level targeting is found as the solution to the following minimisation problem:

$$\begin{array}{c} V_t\left(p_{t-1}, u_t\right) = E_t\left\{\min_{x_t}\left[\frac{1}{2}\left(p_t^2 + \widetilde{\lambda} x_t^2\right) + \beta V_{t+1}\left(p_t, u_{t+1}\right)\right]\right\} \\ s.t.\ \pi_t = \beta E_t \pi_{t+1} + \kappa x_t + u_t. \end{array} \tag{C.1}$$

with u_t being an AR(1) process with autocorrelation coefficient ρ. Since the loss function is quadratic and the constraint is linear, a sensible guess for the value function is

$$V_t\left(p_{t-1}, u_t\right) = \gamma_{0,t} + \gamma_{1,t} p_{t-1} + \frac{1}{2}\gamma_{2,t} p_{t-1}^2 + \gamma_{3,t} p_{t-1} u_t + \gamma_{4,t} u_t + \frac{1}{2}\gamma_{5,t} u_t^2 \tag{C.2}$$

Only the first derivative of the value function $E_t\left[\frac{\partial}{\partial p_t} V_{t+1}\left(p_t, u_{t+1}\right)\right] = \gamma_{1,t+1} + \gamma_{2,t+1} p_t + \gamma_{3,t+1} E_t u_{t+1}$ enters the optimisation problem: accordingly, without loss of generality, $\gamma_{0,t}$, $\gamma_{4,t}$ and $\gamma_{5,t}$ can be set to zero. The same is true for $\gamma_{1,t}$, as long as π^*, x^* and p^* are zero and hence do not appear the first order condition.

As the loss function is quadratic and the constraint linear, the solution for the price level is a linear function

$$p_t = a_t p_{t-1} + b_t u_t \tag{C.3}$$

with coefficents to be determined. The first order condition (FOC) of the problem is

$$E_t\left[p_t\frac{\partial p_t}{\partial x_t}+\widetilde{\lambda}x_t+\beta\frac{\partial}{\partial p_t}V_{t+1}\left(p_t,u_{t+1}\right)\frac{\partial p_t}{\partial x_t}\right]=0. \tag{C.4}$$

To compute $\frac{\partial p_t}{\partial x_t}$, one has to rewrite the Phillips curve using the definition $\pi_t = p_t - p_{t-1}$ and exploiting (C.3) to substitute $E_t p_{t+1}$ with $a_{t+1}p_t + b_{t+1}\rho u_t$, which results in

$$\begin{aligned} p_t &= \beta\left(a_{t+1}p_t+b_{t+1}\rho u_t\right)-\beta p_t+p_{t-1}+\kappa x_t+u_t \\ &= \tfrac{1}{1+\beta(1-a_{t+1})}p_{t-1}+\tfrac{\kappa}{1+\beta(1-a_{t+1})}x_t+\tfrac{1+\beta b_{t+1}\rho}{1+\beta(1-a_{t+1})}u_t. \end{aligned} \tag{C.5}$$

Accordingly, $\frac{\partial p_t}{\partial x_t}=\frac{\kappa}{1+\beta(1-a_{t+1})}$ and the FOC becomes:

$$\begin{aligned} 0 &= E_t\left[\tfrac{\kappa}{1+\beta(1-a_{t+1})}\left(p_t+\beta\left(\gamma_{2,t+1}p_t+\gamma_{3,t+1}u_{t+1}\right)\right)+\widetilde{\lambda}x_t\right] \\ &= p_t+\beta\gamma_{2,t+1}p_t+\beta\gamma_{3,t+1}\rho u_t+\tfrac{\widetilde{\lambda}[1+\beta(1-a_{t+1})]}{\kappa}.x_t \end{aligned} \tag{C.6}$$

To express p_t as a function of the lagged price level p_{t-1} and the supply shock u_t, as in equation (C.3), one has to substitute out x_t, which can be done by inverting equation (C.5), obtaining

$$x_t=\frac{1+\beta\left(1-a_{t+1}\right)}{\kappa}p_t-\frac{1}{\kappa}p_{t-1}-\frac{1+\beta b_{t+1}\rho}{\kappa}. \tag{C.7}$$

Rearranging equation (C.6) one finally obtains:

$$\begin{aligned} p_t &= \tfrac{\widetilde{\lambda}[1+\beta(1-a_{t+1})]}{\kappa^2+\widetilde{\lambda}[1+\beta(1-a_{t+1})]^2+\beta\kappa^2\gamma_{2,t+1}}p_{t-1} \\ &+ \tfrac{\widetilde{\lambda}[1+\beta(1-a_{t+1})](1+\beta b_{t+1}\rho)-\beta\rho\kappa^2\gamma_{3,t+1}}{\kappa^2+\widetilde{\lambda}[1+\beta(1-a_{t+1})]^2+\beta\kappa^2\gamma_{2,t+1}}u_t. \end{aligned} \tag{C.8}$$

The above equation is not yet the equilibrium solution for p_t, because the coefficients $\gamma_{2,t+1}$ and $\gamma_{2,t+1}$ of the value function are not identified. The first step to get rid of them is to apply the envelope theorem, which gives

$$
\begin{array}{rcl}
\frac{\partial}{\partial p_{t-1}}V_t\left(p_{t-1},u_t\right) & = & E_t\left[p_t\frac{\partial p_t}{\partial p_{t-1}}+\beta\frac{\partial}{\partial p_t}V_{t+1}\left(p_t,u_{t+1}\right)\frac{\partial p_t}{\partial p_{t-1}}\right] \\
& = & E_t\left[\widetilde{\lambda}x_t\left(-\frac{1}{\kappa}\right)\right] \\
& = & -\frac{\widetilde{\lambda}}{\kappa^2}\left\{\left[1+\beta\left(1-a_{t+1}\right)\right]p_t-p_{t-1}-\left(1+\beta b_{t+1}\rho\right)u_t\right\} \\
& = & -\frac{\widetilde{\lambda}}{\kappa^2}\left\{\left[1+\beta\left(1-a_{t+1}\right)\right]\left(a_tp_{t-1}+b_tu_t\right)-p_{t-1}-\left(1+\beta b_{t+1}\rho\right)u_t\right\} \\
& = & \frac{\widetilde{\lambda}}{\kappa^2}\left\{1-\left[1+\beta\left(1-a_{t+1}\right)\right]a_t\right\}p_{t-1} \\
& + & \frac{\widetilde{\lambda}}{\kappa^2}\left\{\left(1+\beta b_{t+1}\rho\right)-\left[1+\beta\left(1-a_{t+1}\right)\right]b_t\right\}u_t.
\end{array}
\tag{C.9}
$$

The left-hand side of the above equation can be written as $\frac{\partial}{\partial p_{t-1}}V_t\left(p_{t-1},u_t\right)=\gamma_{2,t}p_{t-1}+\gamma_{3,t}u_t$, implying that

$$
\begin{array}{rcl}
\gamma_{2,t} & = & \frac{\widetilde{\lambda}}{\kappa^2}\left\{1-\left[1+\beta\left(1-a_{t+1}\right)\right]a_t\right\} \\
\gamma_{3,t} & = & \frac{\widetilde{\lambda}}{\kappa^2}\left\{\left(1+\beta b_{t+1}\rho\right)-\left[1+\beta\left(1-a_{t+1}\right)\right]b_t\right\}.
\end{array}
\tag{C.10}
$$

Using the above equations, I can rewrite equation (C.8) as

$$
\begin{array}{rcl}
p_t & = & \frac{\widetilde{\lambda}[1+\beta(1-a_{t+1})]}{\kappa^2+\widetilde{\lambda}[1+\beta(1-a_{t+1})]^2+\beta\widetilde{\lambda}\{1-[1+\beta(1-a_{t+2})]a_{t+1}\}}p_{t-1} \\
& + & \frac{\widetilde{\lambda}[1+\beta(1-a_{t+1})](1+\beta b_{t+1}\rho)-\beta\rho\widetilde{\lambda}\{(1+\beta b_{t+1}\rho)-[1+\beta(1-a_{t+2})]b_{t+1}\}}{\kappa^2+\widetilde{\lambda}[1+\beta(1-a_{t+1})]^2+\beta\widetilde{\lambda}\{1-[1+\beta(1-a_{t+2})]a_{t+1}\}}u_t
\end{array}
\tag{C.11}
$$

from which it follows that

$$
\begin{array}{rcl}
a_t & = & \frac{\widetilde{\lambda}[1+\beta(1-a_{t+1})]}{\kappa^2+\widetilde{\lambda}[1+\beta(1-a_{t+1})]^2+\beta\widetilde{\lambda}\{1-[1+\beta(1-a_{t+2})]a_{t+1}\}} \\
b_t & = & \frac{\widetilde{\lambda}[1+\beta(1-a_{t+1})](1+\beta b_{t+1}\rho)-\beta\rho\widetilde{\lambda}\{(1+\beta b_{t+1}\rho)-[1+\beta(1-a_{t+2})]b_{t+1}\}}{\kappa^2+\widetilde{\lambda}[1+\beta(1-a_{t+1})]^2+\beta\widetilde{\lambda}\{1-[1+\beta(1-a_{t+2})]a_{t+1}\}}.
\end{array}
\tag{C.12}
$$

Iterating the two equations above, one eventually converges to the solution

$$
p_t=\widetilde{a}p_{t-1}+\widetilde{b}u_t \tag{C.13}
$$

which implies that:

$$
\begin{array}{rcl}
\widetilde{a} & = & \frac{\widetilde{\lambda}\omega}{\kappa^2+\omega^2+\beta\widetilde{\lambda}\{1-\omega\widetilde{a}\}} \\
\widetilde{b} & = & \frac{\widetilde{\lambda}\omega\left(1+\beta\widetilde{b}\rho\right)-\beta\rho\widetilde{\lambda}\left\{\left(1+\beta\widetilde{b}\rho\right)-\omega\widetilde{b}\right\}}{\kappa^2+\widetilde{\lambda}\omega^2+\beta\widetilde{\lambda}\{1-[1+\beta(1-a_{t+2})]a_{t+1}\}}
\end{array}
\tag{C.14}
$$

where $\omega=1+\beta\left(1-\widetilde{a}\right)$.

By properly rearranging the Phillips curve, it is possible to find a symmetric expression for x_t, namely $x_t = -\widetilde{c}p_{t-1} - \widetilde{d}u_t$. Using (C.13), the Phillips curve can be written as

$$p_t \quad = \quad \beta\left(\widetilde{a}p_t + \widetilde{b}\rho u_t\right) - \beta p_t + p_{t-1} + \kappa x_t + u_t.$$

Moving all terms different from x_t on the left-hand side and then using (C.13) again

$$\begin{aligned}
(1+\beta-\beta\widetilde{a})\,p_t - p_{t-1} - \left(1+\beta\widetilde{b}\rho\right)u_t &= \kappa x_t \\
[1+\beta\,(1-\widetilde{a})]\left(\widetilde{a}p_{t-1} + \widetilde{b}u_t\right) - p_{t-1} - \left(1+\beta\widetilde{b}\rho\right)u_t &= \kappa x_t.
\end{aligned}$$

Rearranging and dividing both side by κ, one finally obtains

$$\begin{aligned}
x_t &= -\frac{(1-\widetilde{a})\left(1-\widetilde{\beta a}\right)}{\kappa}p_{t-1} - \frac{1-\widetilde{b}[1+\beta\,(1-\rho-\widetilde{a})]}{\kappa}u_t \\
&= -\widetilde{c}p_{t-1} - \widetilde{d}u_t.
\end{aligned} \tag{C.15}$$

Appendix D

Average inflation targeting under discretion

A j-period average inflation targeting (AITj) monetary policy strategy introduces $j-1$ state variables in the model. To keep the problem tractable and be able to derive the analytical solution, it is assumed that $j=2$.

The equilibrium under AIT2 is found by solving the following minimisation problem:

$$\begin{gathered} V_t\left(\pi_{t-1},u_t\right) = E_t\left\{\min_{x_t} \tfrac{1}{2}\left[\left(\tfrac{\pi_t+\pi_{t-1}}{2}\right)^2 + \overline{\lambda}x_t^2\right] + \beta V_{t+1}\left(\pi_t,u_{t+1}\right)\right\} \\ s.t.\ \pi_t = \beta E_t\pi_{t+1} + \kappa x_t + u_t \end{gathered} \tag{D.1}$$

with u_t being an AR(1) process with autocorrelation coefficient ρ. A tentative guess for the value function is

$$V_t\left(\pi_{t-1},u_t\right) = \gamma_{0,t} + \gamma_{1,t}\pi_{t-1} + \frac{1}{2}\gamma_{2,t}\pi_{t-1}^2 + \gamma_{3,t}\pi_{t-1}u_t + \gamma_{4,t}u_t + \frac{1}{2}\gamma_{5,t}u_t^2. \tag{D.2}$$

Not all the parameters of the value function are needed: since only the first partial derivative with respect to π_{t-1} matters, $\gamma_{0,t}$, $\gamma_{4,t}$ and $\gamma_{5,t}$ can be safely ignored and assumed to be equal to zero. The same applies to $\gamma_{1,t}$, which is relevant only if the target inflation rate is positive, while for simplicity - and only for the purpose of deriving the analytical solution to the minimisation problem - I assume that it is zero.

The solution to be found for the inflation rate will be of the form

$$\pi_t = a_t \pi_{t-1} + b_t u_t. \tag{D.3}$$

The first order condition for the optimisation problem is:

$$\frac{1}{2}\left(\frac{\pi_t + \pi_{t-1}}{2}\right)\frac{\partial \pi_t}{\partial x_t} + \overline{\lambda} x_t + \beta E_t\left[\frac{\partial}{\partial \pi_t} V_{t+1}\left(\pi_t, u_{t+1}\right)\frac{\partial \pi_t}{\partial x_t}\right] = 0. \tag{D.4}$$

Since $E_t\left[\frac{\partial}{\partial \pi_t} V_{t+1}\left(\pi_t, u_{t+1}\right)\right] = \gamma_{2,t+1}\pi_t + \gamma_{3,t+1} E_t u_{t+1}$, the FOC can be also written as

$$\begin{aligned} \left[\tfrac{\pi_t + \pi_{t-1}}{4} + \beta\left(\gamma_{2,t+1}\pi_t + \gamma_{3,t+1}\rho u_t\right)\right]\tfrac{\partial \pi_t}{\partial x_t} + \overline{\lambda} x_t &= 0 \\ \left[\left(\tfrac{1}{4} + \beta\gamma_{2,t+1}\right)\pi_t + \tfrac{\pi_{t-1}}{4} + \beta\gamma_{3,t+1}\rho u_t\right]\tfrac{\kappa}{1-\beta a_{t+1}} + \overline{\lambda} x_t &= 0. \end{aligned} \tag{D.5}$$

The last equality has used the fact that, according to (D.3), $E_t \pi_{t+1} = a_{t+1}\pi_t + b_{t+1}\rho u_t$ and hence the Phillips curve can be rewritten as

$$\pi_t = \frac{\kappa}{1 - \beta a_{t+1}} x_t + \frac{1 + \beta\rho b_{t+1}}{1 - \beta a_{t+1}} u_t \tag{D.6}$$

where $\frac{\partial \pi_t}{\partial x_t} = \frac{\kappa}{1-\beta a_{t+1}}$. To get rid of x_t in the FOC, the above equation can be inverted, expressing x_t as a function of π_t and u_t. The FOC becomes therefore

$$\begin{aligned} 0 &= \left[\left(\tfrac{1}{4} + \beta\gamma_{2,t+1}\right)\pi_t + \tfrac{\pi_{t-1}}{4} + \beta\gamma_{3,t+1}\rho u_t\right]\tfrac{\kappa}{1-\beta a_{t+1}} \\ &+ \overline{\lambda}\left(\tfrac{1-\beta a_{t+1}}{\kappa}\pi_t - \tfrac{1+\beta\rho b_{t+1}}{\kappa} u_t\right) \\ 0 &= \left[\tfrac{\kappa^2\left(1+4\beta\gamma_{2,t+1}\right)+4\overline{\lambda}\left(1-\beta a_{t+1}\right)^2}{4\kappa\left(1-\beta a_{t+1}\right)}\right]\pi_t + \tfrac{\kappa}{4\left(1-\beta a_{t+1}\right)}\pi_{t-1} \\ &+ \tfrac{\beta\gamma_{3,t+1}\rho\kappa^2 - \overline{\lambda}\left(1+\beta\rho b_{t+1}\right)\left(1-\beta a_{t+1}\right)}{\kappa\left(1-\beta a_{t+1}\right)} u_t. \end{aligned} \tag{D.7}$$

Solving for π_t gives

$$\begin{aligned} \pi_t &= -\tfrac{\kappa^2}{\kappa^2\left(1+4\beta\gamma_{2,t+1}\right)+4\overline{\lambda}\left(1-\beta a_{t+1}\right)^2}\pi_{t-1} \\ &+ \tfrac{4\overline{\lambda}\left(1+\beta\rho b_{t+1}\right)\left(1-\beta a_{t+1}\right)-4\beta\gamma_{3,t+1}\rho\kappa^2}{\kappa^2\left(1+4\beta\gamma_{2,t+1}\right)+4\overline{\lambda}\left(1-\beta a_{t+1}\right)^2} u_t \end{aligned} \tag{D.8}$$

which depends on the unknown coefficients $\gamma_{2,t+1}$ and $\gamma_{3,t+1}$. To substitute them out, one can use (D.2) and the envelope theorem, resulting in

$$
\begin{aligned}
\frac{\partial}{\partial \pi_{t-1}} V_t\left(\pi_{t-1}, u_t\right) &= \frac{\pi_t+\pi_{t-1}}{4} \\
\gamma_{2,t}\pi_{t-1}+\gamma_{3,t}u_t &= \frac{a_t\pi_{t-1}+b_tu_t+\pi_{t-1}}{4} \\
&= \frac{1+a_t}{4}\pi_{t-1}+\frac{b_t}{4}u_t
\end{aligned}
$$

implying that

$$
\begin{aligned}
\gamma_{2,t} &= \frac{1+a_t}{4} \\
\gamma_{3,t} &= \frac{b_t}{4}.
\end{aligned} \tag{D.9}
$$

Using the above equations led once, I can rewrite equation (D.8) as

$$
\begin{aligned}
\pi_t &= -\frac{\kappa^2}{\kappa^2(1+\beta(1+a_t))+4\bar{\lambda}(1-\beta a_{t+1})^2}\pi_{t-1} \\
&+ \frac{4\bar{\lambda}(1+\beta\rho b_{t+1})(1-\beta a_{t+1})-\beta b_{t+1}\rho\kappa^2}{\kappa^2(1+\beta(1+a_t))+4\bar{\lambda}(1-\beta a_{t+1})^2}u_t
\end{aligned} \tag{D.10}
$$

from which it follows that the two unknown coefficients in equation (D.3) are obtained from the following equations:

$$
\begin{aligned}
a_t &= -\frac{\kappa^2}{\kappa^2(1+\beta(1+a_t))+4\bar{\lambda}(1-\beta a_{t+1})^2} \\
b_t &= \frac{4\bar{\lambda}(1+\beta\rho b_{t+1})(1-\beta a_{t+1})-\beta b_{t+1}\rho\kappa^2}{\kappa^2(1+\beta(1+a_t))+4\bar{\lambda}(1-\beta a_{t+1})^2}.
\end{aligned} \tag{D.11}
$$

Iterating the system (D.11), one eventually converges to the solution

$$
\pi_t = \bar{a}\pi_{t-1}+\bar{b}u_t. \tag{D.12}
$$

By properly rearranging the Phillips curve (D.6), it is possible to find a symmetric expression for x_t, namely $x_t = -\bar{c}p_{t-1}-\bar{d}u_t$:

$$
\begin{aligned}
x_t &= \frac{1-\beta\bar{a}}{\kappa}\pi_t - \frac{1+\beta\rho\bar{b}}{\kappa}u_t \\
&= \frac{1-\beta\bar{a}}{\kappa}\left(\bar{a}\pi_{t-1}+\bar{b}u_t\right) - \frac{1+\beta\rho\bar{b}}{\kappa}u_t \\
&= \frac{\bar{a}(1-\beta\bar{a})}{\kappa}\pi_{t-1} + \frac{\bar{b}(1-\beta\bar{a})-\left(1+\beta\rho\bar{b}\right)}{\kappa}u_t \\
&= -\frac{\bar{a}(\beta\bar{a}-1)}{\kappa}\pi_{t-1} - \frac{1-\bar{b}(1-\beta(\bar{a}+\rho))}{\kappa}u_t
\end{aligned}
$$

where

$$
\begin{aligned}
\overline{c} &= \tfrac{\overline{a}(\beta\overline{a}-1)}{\kappa} \\
\overline{d} &= \tfrac{1-\overline{b}(1-\beta(\overline{a}+\rho))}{\kappa}.
\end{aligned}
$$

Appendix E

Dynare codes

E.1 Commitment

```
var pi x i u_cit;
varexo eps;
parameters sigma psi chi beta kappa r_nat pi_target rho lambda;
sigma=0.53;
psi = 0.72;
chi = 0.70;
beta=0.9975;
kappa=0.05;
lambda=0.048;
r_nat = 0.25;
pi_target=0.5;
rho = 0.75;
// Model //
model(linear);
//1.  New Keynesian sigmallips Curve
pi=(1-psi)*pi(-1)+psi*pi(+1)+kappa*x+u_cit;
//2.  Dynamic IS Curve
x=(1-chi)*x(-1)+chi*x(+1)-sigma*(i-pi(+1)-r_nat);
//3.  Cost-Push Shock
u_cit=rho*u_cit(-1)+eps;
end;
// Shocks //
shocks;
var eps = 0.06^2;
end;
planner_objective (pi-pi_target)^2+lambda*x^2; % central bank's loss function
(3.3)
```

```
ramsey_policy(instruments=(i),planner_discount=beta) pi x i u_cit;
steady;
//Calculations
set_dynare_seed('default');
pi_sim=zeros(200,1000);
x_sim=zeros(200,1000);
i_cit_sim=zeros(200,1000);
u_cit_sim=zeros(200,1000);
n_replic=1000;
n_per=200;
idx = 0;
for j=1:n_replic
set_dynare_seed(j);
stoch_simul(periods=200, noprint, nograph) pi x i u_cit;
pi_cit_sim(:,j) = pi;
y_cit_sim(:,j) = x;
i_cit_sim(:,j) = i;
u_cit_sim(:,j) = u_cit;
A_it = any(i_cit_sim<0,1);
end
varcIT_pi = sum(sum((pi_sim-pi_target).^2)/n_per)/n_replic;
varcIT_x = sum(sum(x_sim.
textasciicircum 2)/n_per)/n_replic;
varcIT_i = sum(sum((i_cit_sim-i_target).^2)/n_per)/n_replic;
meancIT_pi = sum(mean(pi_sim))/n_replic;
meancIT_x = sum(mean(x_sim))/n_replic;
meancIT_i = sum(mean(i_cit_sim))/n_replic;
// Probability of hitting the ZLB at least once in the next 200 quarters (or
20 years)
P_cIT = sum(any(i_cit_sim<0,1));
// FREQUENCY OF HITTING THE ZLB FOR IT WITH 2% TARGET UNDER COMMITMENT
FrZLB_cIT = mean(sum(i_cit_sim<0)/n_per)*100; // frequency in percentage terms
idx = 0;
zfreq_cIT=zeros(idx,n_replic);
for j=1:n_replic  idx = 0;
for i=2:200
if i_cit_sim(i,j)<0 && i_cit_sim(i-1,j)<0
idx = idx + 1;
zfreq_cIT(idx,j)=i;
end
end
end
// I want to find the mean and max length of ZLB episode in each replication
```

```
id=[zeros(1,n_replic);i_cit_sim<0]
meanlength=zeros(1,n_replic);
maxlength=zeros(1,n_replic);
for j=1:n_replic
ii1=strfind(id(:,j)',[0 1]); % finds the start of the episode (must be at least
3 consecutive quarters)
ii2=strfind([id(:,j)' 0],[1 0]); % finds the end of the episode
length=ii2-ii1; % calculates the length of each episode per replication
meanlength=mean(length);
max_length=max(length); % calculates the maximum duration of the episode
if isempty(max_length) % throw out the "too short" episodes with the loop
max_length=0;
end
meanlength_cIT(:,j) = meanlength;
maxlength_cIT(:,j) = max_length;
end
meanlengthZLB_cIT = mean(meanlength_cIT);
maxlengthZLB_cIT = max(maxlength_cIT);
L_cIT = sum(mean((pi_cit_sim-pi_target).^2+lambda*x_sim.^2))/n_replic; % society's
loss function
```

E.2 Inflation targeting (2% target)

```
var pi x i u_IT;
varexo eps;
parameters sigma psi chi beta kappa r_nat pi_target rho lambda;
sigma=0.53;
psi = 0.72;
chi = 0.70;
beta=0.9975;
kappa=0.05;
lambda=0.048;
r_nat = 0.25;
pi_target=0.5;
rho = 0.75;
// Model //
model(linear);
//1. New Keynesian sigmallips Curve
pi_dev=(1-psi)*pi_dev(-1)+psi*pi_dev(+1)+kappa*x+u_IT;
//2. Dynamic IS Curve
x=(1-chi)*x(-1)+chi*x(+1)-sigma*(i_dev-pi_dev(+1));
```

```
//3.  Cost-Push Shock
u_IT=rho*u_IT(-1)+eps;
end;
// Shocks //
shocks;
var eps = 0.06^2;
end;
planner_objective pi_dev^2+lambda*x^2; % central bank's loss function (3.3)
discretionary_policy(instruments=(i_dev),planner_discount=beta) pi_dev x i_dev
u_IT;
steady;
//Calculations
set_dynare_seed('default');
pi_dev_sim=zeros(200,1000);
x_sim=zeros(200,1000);
i_dev_sim=zeros(200,1000);
u_IT_sim=zeros(200,1000);
n_replic=1000;
n_per=200;
idx = 0;
for j=1:n_replic
set_dynare_seed(j);
stoch_simul(periods=200, noprint, nograph) pi x i u_IT;
pi_dev_sim(:,j) = pi_dev;
x_sim(:,j) = x;
i_dev_sim(:,j) = i_dev;
u_IT_sim(:,j) = u_IT;
end
i_target=r_nat+pi_target;
i_IT_sim = i_dev_sim+i_target;
pi_IT_sim=pi_dev_sim+pi_target;
varIT_pi = sum(sum((pi_IT_sim-pi_target).^2)/n_per)/n_replic;
varIT_x = sum(sum(x_sim.^2)/n_per)/n_replic;
varIT_i = sum(sum((i_IT_sim-i_target).^2)/n_per)/n_replic;
meanIT_pi = sum(mean(pi_IT_sim))/n_replic;
meanIT_x = sum(mean(x_sim))/n_replic;
meanIT_i = sum(mean(i_IT_sim))/n_replic;
// Probability of hitting the ZLB at least once in the next 200 quarters (or
20 years)
P_IT = sum(any(i_IT_sim<0,1));
// FREQUENCY OF HITTING THE ZLB FOR IT WITH 2% TARGET UNDER DISCRETION
FrZLB_IT = mean(sum(i_IT_sim<0)/n_per)*100; // frequency in percentage terms
idx = 0;
```

```
zfreq_IT=zeros(idx,n_replic);
for j=1:n_replic
idx = 0;
for i=2:200
if i_IT_sim(i,j)<0 && i_IT_sim(i-1,j)<0
idx = idx + 1;
zfreq_IT(idx,j)=i;
end
end
end
// I want to find the mean and max length of ZLB episode in each replication
id=[zeros(1,n_replic);i_IT_sim<0]
meanlength=zeros(1,n_replic);
maxlength=zeros(1,n_replic);
for j=1:n_replic
ii1=strfind(id(:,j)',[0 1]); % finds the start of the episode (must be at least
3 consecutive quarters)
ii2=strfind([id(:,j)' 0],[1 0]); % finds the end of the episode
length=ii2-ii1; % calculates the length of each episode per replication
meanlength=mean(length);
max_length=max(length); % calculates the maximum duration of the episode
if isempty(max_length) % throw out the "too short" episodes with the loop
max_length=0;
end
meanlength_IT(:,j) = meanlength;
maxlength_IT(:,j) = max_length;
end
meanlengthZLB_IT = mean(meanlength_IT);
maxlengthZLB_IT = max(maxlength_IT);
L_IT = sum(mean(pi_dev_sim.^2+lambda*x_sim.^2))/n_replic; % society's loss
function
```

E.3 Price-level targeting

```
var pi x i u_PT;
varexo eps;
parameters sigma psi chi beta kappa r_nat pi_target rho lambda;
sigma=0.53;
psi = 0.72;
chi = 0.70;
beta=0.9975;
```

```
kappa=0.05;
lambda=0.048;
r_nat = 0.25;
pi_target=0.5;
rho = 0.75;
// Model //
model(linear);
//1.  New Keynesian sigmallips Curve
pi_dev=(1-psi)*pi_dev(-1)+psi*pi_dev(+1)+kappa*x+u_PT;
//2.  Dynamic IS Curve
x=(1-chi)*x(-1)+chi*x(+1)-sigma*(i_dev-pi_dev(+1));
//3.  Cost-Push Shock
u_PT=rho*u_PT(-1)+eps;
//4.  Identity
pi_dev=p_dev-p_dev(-1);
end;
// Shocks //
shocks;
var eps = 0.06^2;
end;
planner_objective p_dev^2+lambda*x^2; % central bank's loss function (3.4)
discretionary_policy(instruments=(i_dev),planner_discount=beta) pi_dev x i_dev
u_PT p_dev;
steady;
//Calculations
set_dynare_seed('default');
pi_dev_sim=zeros(200,1000);
x_sim=zeros(200,1000);
i_dev_sim=zeros(200,1000);
u_PT_sim=zeros(200,1000);
p_dev_sim=zeros(200,1000);
n_replic=1000;
n_per=200;
idx = 0;
for j=1:n_replic
set_dynare_seed(j);
stoch_simul(periods=200, noprint, nograph) pi x i u_PT;
pi_dev_sim(:,j) = pi_dev;
x_sim(:,j) = x;
i_dev_sim(:,j) = i_dev;
u_PT_sim(:,j) = u_PT;
p_dev_sim(:,j) = p_dev;
end
```

```
i_target=r_nat+pi_target;
i_PT_sim = i_dev_sim+i_target;
pi_PT_sim=pi_dev_sim+pi_target;
varPT_pi = sum(sum((pi_PT_sim-pi_target).^2)/n_per)/n_replic;
varPT_x = sum(sum(x_sim.^2)/n_per)/n_replic;
varPT_i = sum(sum((i_PT_sim-i_target).^2)/n_per)/n_replic;
meanPT_pi = sum(mean(pi_PT_sim))/n_replic;
meanPT_x = sum(mean(x_sim))/n_replic;
meanPT_i = sum(mean(i_PT_sim))/n_replic;
// Probability of hitting the ZLB at least once in the next 200 quarters (or
20 years)
P_PT = sum(any(i_PT_sim<0,1));
// FREQUENCY OF HITTING THE ZLB FOR PLT
FrZLB_PT = mean(sum(i_PT_sim<0)/n_per)*100; // frequency in percentage terms
idx = 0;
zfreq_PT=zeros(idx,n_replic);
for j=1:n_replic
idx = 0;
for i=2:200
if i_PT_sim(i,j)<0 && i_PT_sim(i-1,j)<0
idx = idx + 1;
zfreq_PT(idx,j)=i;
end
end
end
// I want to find the mean and max length of ZLB episode in each replication
id=[zeros(1,n_replic);i_PT_sim<0]
meanlength=zeros(1,n_replic);
maxlength=zeros(1,n_replic);
for j=1:n_replic
ii1=strfind(id(:,j)',[0 1]); % finds the start of the episode (must be at least
3 consecutive quarters)
ii2=strfind([id(:,j)' 0],[1 0]); % finds the end of the episode
length=ii2-ii1; % calculates the length of each episode per replication
meanlength=mean(length);
max_length=max(length); % calculates the maximum duration of the episode
if isempty(max_length) % throw out the "too short" episodes with the loop
max_length=0;
end
meanlength_PT(:,j) = meanlength;
maxlength_PT(:,j) = maxlength;
end
meanlengthZLB_IT = mean(meanlength_IT);
```

```
maxlengthZLB_IT = max(maxlength_IT);
L_PT = sum(mean(pi_dev_sim.^2+lambda*x_sim.^2))/n_replic; % society's loss
function
```

E.4 Inflation targeting (4% target)

```
var pi x i u_IT4;
varexo eps;
parameters sigma psi chi beta kappa r_nat pi_target rho lambda;
sigma=0.53;
psi = 0.72;
chi = 0.70;
beta=0.9975;
kappa=0.05;
lambda=0.048;
r_nat = 0.25;
pi_target=0.5;
rho = 0.75;
// Model //
model(linear);
//1.  New Keynesian sigmallips Curve
pi_dev=(1-psi)*pi_dev(-1)+psi*pi_dev(+1)+kappa*x+u_IT4;
//2.  Dynamic IS Curve
x=(1-chi)*x(-1)+chi*x(+1)-sigma*(i_dev-pi_dev(+1));
//3.  Cost-Push Shock
u_IT4=rho*u_IT4(-1)+eps;
end;
// Shocks //
shocks;
var eps = 0.06^2;
end;
planner_objective pi_dev^2+lambda*x^2; % central bank's loss function
discretionary_policy(instruments=(i_dev),planner_discount=beta) pi_dev x i_dev
u_IT4;
steady;
//Calculations
set_dynare_seed('default');
pi_dev_sim=zeros(200,1000);
x_sim=zeros(200,1000);
i_dev_sim=zeros(200,1000);
u_IT4_sim=zeros(200,1000);
```

```
n_replic=1000;
n_per=200;
idx = 0;
for j=1:n_replic
set_dynare_seed(j);
stoch_simul(periods=200, noprint, nograph) pi x i u_IT4;
pi_dev_sim(:,j) = pi_dev;
x_sim(:,j) = x;
i_dev_sim(:,j) = i_dev;
u_IT4_sim(:,j) = u_IT4;
end
i_target=r_nat+pi_target;
i_IT4_sim = i_dev_sim+i_target;
pi_IT4_sim=pi_dev_sim+pi_target;
varIT4_pi = sum(sum((pi_IT4_sim-pi_target).^2)/n_per)/n_replic;
varIT4_x = sum(sum(x_sim.^2)/n_per)/n_replic;
varIT4_i = sum(sum((i_IT4_sim-i_target).^2)/n_per)/n_replic;
meanIT4_pi = sum(mean(pi_IT4_sim))/n_replic;
meanIT4_x = sum(mean(x_sim))/n_replic;
meanIT4_i = sum(mean(i_IT4_sim))/n_replic;
// Probability of hitting the ZLB at least once in the next 200 quarters (or
20 years)
P_IT4 = sum(any(i_IT4_sim<0,1));
// FREQUENCY OF HITTING THE ZLB FOR IT WITH 4% TARGET
FrZLB_IT4 = mean(sum(i_IT4_sim<0)/n_per)*100; // frequency in percentage terms
idx = 0;
zfreq_IT4=zeros(idx,n_replic);
for j=1:n_replic
idx = 0;
for i=2:200
if i_IT4_sim(i,j)<0 && i_IT4_sim(i-1,j)<0
idx = idx + 1;
zfreq_IT4(idx,j)=i;
end
end
end
// I want to find the mean and max length of ZLB episode in each replication
id=[zeros(1,n_replic);i_IT4_sim<0]
meanlength=zeros(1,n_replic);
maxlength=zeros(1,n_replic);
for j=1:n_replic
ii1=strfind(id(:,j)',[0 1]); % finds the start of the episode (must be at least
3 consecutive quarters)
```

```
ii2=strfind([id(:,j)' 0],[1 0]); % finds the end of the episode
length=ii2-ii1; % calculates the length of each episode per replication
meanlength=mean(length);
max_length=max(length); % calculates the maximum duration of the episode
if isempty(max_length) % throw out the "too short" episodes with the loop
max_length=0;
end
meanlength_IT4(:,j) = meanlength;
maxlength_IT4(:,j) = max_length;
end
meanlengthZLB_IT4 = mean(meanlength_IT4);
maxlengthZLB_IT4 = max(maxlength_IT4);
L_IT4 = sum(mean(pi_dev_sim.^2+lambda*x_sim.^2))/n_replic; % society's loss
function
```

E.5 Average inflation targeting (8 periods)

```
var pi x i u_AIT8;
varexo eps;
parameters sigma psi chi beta kappa r_nat pi_target rho lambda;
sigma=0.53;
psi = 0.72;
chi = 0.70;
beta=0.9975;
kappa=0.05;
lambda=0.048;
r_nat = 0.25;
pi_target=0.5;
rho = 0.75;
// Model //
model(linear);
//1. New Keynesian sigmallips Curve
pi_dev=(1-psi)*pi_dev(-1)+psi*pi_dev(+1)+kappa*x+u_AIT8;
//2. Dynamic IS Curve
x=(1-chi)*x(-1)+chi*x(+1)-sigma*(i_dev-pi_dev(+1));
//3. Cost-Push Shock
u_AIT8=rho*u_AIT8(-1)+eps;
//4. Average of inflation measured over 8 periods (equivalent to 2 years)
pi_av = 1/8*(pi_dev+pi_dev(-1)+pi_dev(-2)+pi_dev(-3)+pi_dev(-4)+pi_dev(-5)+pi_dev(-6)+
+pi_dev(-7));
end;
```

```
// Shocks //
shocks;
var eps = 0.06^2;
end;
planner_objective pi_av^2+lambda*x^2; % central bank's loss function (3.5)
discretionary_policy(instruments=(i_dev),planner_discount=beta) pi_dev x i_dev
u_AIT8 pi_av;
steady;
//Calculations
set_dynare_seed('default');
pi_dev_sim=zeros(200,1000);
x_sim=zeros(200,1000);
i_dev_sim=zeros(200,1000);
u_AIT8_sim=zeros(200,1000);
pi_av8_sim=zeros(200,1000);
n_replic=1000;
n_per=200;
idx = 0;
for j=1:n_replic
set_dynare_seed(j);
stoch_simul(periods=200, noprint, nograph) pi x i u_AIT8;
pi_dev_sim(:,j) = pi_dev;
x_sim(:,j) = x;
i_dev_sim(:,j) = i_dev;
u_AIT8_sim(:,j) = u_AIT8;
pi_av8_sim(:,j) = pi_av;
end
i_target=r_nat+pi_target;
i_AIT8_sim = i_dev_sim+i_target;
pi_AIT8_sim=pi_dev_sim+pi_target;
varAIT8_pi = sum(sum((pi_AIT8_sim-pi_target).^2)/n_per)/n_replic;
varAIT8_x = sum(sum(x_sim.^2)/n_per)/n_replic;
varAIT8_i = sum(sum((i_AIT8_sim-i_target).^2)/n_per)/n_replic;
meanAIT8_pi = sum(mean(pi_AIT8_sim))/n_replic;
meanAIT8_x = sum(mean(x_sim))/n_replic;
meanAIT8_i = sum(mean(i_AIT8_sim))/n_replic;
// Probability of hitting the ZLB at least once in the next 200 quarters (or
20 years)
P_AIT8 = sum(any(i_AIT8_sim<0,1));
// FREQUENCY OF HITTING THE ZLB FOR 8-period AIT
FrZLB_AIT8 = mean(sum(i_AIT8_sim<0)/n_per)*100; // frequency in percentage
terms
idx = 0;
```

```
zfreq_AIT8=zeros(idx,n_replic);
for j=1:n_replic
idx = 0;
for i=2:200
if i_AIT8_sim(i,j)<0 && i_AIT8_sim(i-1,j)<0
idx = idx + 1;
zfreq_AIT8(idx,j)=i;
end
end
end
// I want to find the mean and max length of ZLB episode in each replication
id=[zeros(1,n_replic);i_AIT8_sim<0]
meanlength=zeros(1,n_replic);
maxlength=zeros(1,n_replic);
for j=1:n_replic
ii1=strfind(id(:,j)',[0 1]); % finds the start of the episode (must be at least
3 consecutive quarters)
ii2=strfind([id(:,j)' 0],[1 0]); % finds the end of the episode
length=ii2-ii1; % calculates the length of each episode per replication
meanlength=mean(length);
max_length=max(length); % calculates the maximum duration of the episode
if isempty(max_length) % throw out the "too short" episodes with the loop
max_length=0;
end
meanlength_AIT8(:,j) = meanlength;
maxlength_AIT8(:,j) = maxlength;
end
meanlengthZLB_AIT8 = mean(meanlength_AIT8);
maxlengthZLB_AIT8 = max(maxlength_AIT8);
L_AIT8 = sum(mean(pi_av8_sim.^2+lambda*x_sim.^2))/n_replic; % society's loss
function
```

E.6 Average inflation targeting (12 periods)

```
var pi x i u_AIT12;
varexo eps;
parameters sigma psi chi beta kappa r_nat pi_target rho lambda;
sigma=0.53;
psi = 0.72;
chi = 0.70;
beta=0.9975;
```

```
kappa=0.05;
lambda=0.048;
r_nat = 0.25;
pi_target=0.5;
rho = 0.75;
// Model //
model(linear);
//1.  New Keynesian sigmallips Curve
pi_dev=(1-psi)*pi_dev(-1)+psi*pi_dev(+1)+kappa*x+u_AIT12;
//2.  Dynamic IS Curve
x=(1-chi)*x(-1)+chi*x(+1)-sigma*(i_dev-pi_dev(+1));
//3.  Cost-Push Shock
u_AIT12=rho*u_AIT12(-1)+eps;
//4.  Average of inflation measured over 12 periods (equivalent to 3 years)
pi_av = 1/8*(pi_dev+pi_dev(-1)+pi_dev(-2)+pi_dev(-3)+pi_dev(-4)+pi_dev(-5)+pi_dev(-6)+
+pi_dev(-7)+pi_dev(-8)+pi_dev(-9)+pi_dev(-10)+pi_dev(-11));
end;
// Shocks //
shocks;
var eps = 0.06^2;
end;
planner_objective pi_av^2+lambda*x^2; % central bank's loss funtion (3.5)
discretionary_policy(instruments=(i_dev),planner_discount=beta) pi_dev x i_dev
u_AIT12 pi_av;
steady;
//Calculations
set_dynare_seed('default');
pi_dev_sim=zeros(200,1000);
x_sim=zeros(200,1000);
i_dev_sim=zeros(200,1000);
u_AIT12_sim=zeros(200,1000);
pi_av_sim=zeros(200,1000);
n_replic=1000;
n_per=200;
idx = 0;
for j=1:n_replic
set_dynare_seed(j);
stoch_simul(periods=200, noprint, nograph) pi x i u_AIT12;
pi_dev_sim(:,j) = pi_dev;
x_sim(:,j) = x;
i_dev_sim(:,j) = i_dev;
u_AIT12_sim(:,j) = u_AIT12;
pi_av12_sim(:,j) = pi_av;
```

```
end
i_target=r_nat+pi_target;
i_AIT12_sim = i_dev_sim+i_target;
pi_AIT12_sim=pi_dev_sim+pi_target;
varAIT12_pi = sum(sum((pi_AIT12_sim-pi_target).^2)/n_per)/n_replic;
varAIT12_x = sum(sum(x_sim.^2)/n_per)/n_replic;
varAIT12_i = sum(sum((i_AIT12_sim-i_target).^2)/n_per)/n_replic;
meanAIT12_pi = sum(mean(pi_AIT12_sim))/n_replic;
meanAIT12_x = sum(mean(x_sim))/n_replic;
meanAIT12_i = sum(mean(i_AIT12_sim))/n_replic;
// Probability of hitting the ZLB at least once in the next 200 quarters (or
20 years)
P_AIT12 = sum(any(i_AIT12_sim<0,1));
// FREQUENCY OF HITTING THE ZLB FOR 12-period AIT
FrZLB_AIT12 = mean(sum(i_AIT12_sim<0)/n_per)*100; // frequency in percentage
terms
idx = 0;
zfreq_AIT12=zeros(idx,n_replic);
for j=1:n_replic
idx = 0;
for i=2:200
if i_AIT12_sim(i,j)<0 && i_AIT12_sim(i-1,j)<0
idx = idx + 1;
zfreq_AIT12(idx,j)=i;
end
end
end
// I want to find the mean and max length of ZLB episode in each replication
id=[zeros(1,n_replic);i_AIT12_sim<0]
meanlength=zeros(1,n_replic);
maxlength=zeros(1,n_replic);
for j=1:n_replic
ii1=strfind(id(:,j)',[0 1]); % finds the start of the episode (must be at least
3 consecutive quarters)
ii2=strfind([id(:,j)' 0],[1 0]); % finds the end of the episode
length=ii2-ii1; % calculates the length of each episode per replication
meanlength=mean(length);
maxlength=max(length); % calculates the maximum duration of the episode
if isempty(max_length) % throw out the "too short" episodes with the loop
max_length=0;
end
meanlength_AIT12(:,j) = meanlength;
maxlength_AIT12(:,j) = maxlength;
```

```
end
meanlengthZLB_AIT12 = mean(meanlength_AIT12);
maxlengthZLB_AIT12 = max(maxlength_AIT12);
L_AIT12 = sum(mean(pi_av12_sim.^2+lambda*x_sim.^2))/n_replic; % society's loss
function
```

Appendix F

Abbreviations table

Abbreviations table	
Average inflation targeting	AIT
Dynamic stochastic general equilibrium	DSGE
Effective lower bound	ELB
First order condition	FOC
Global financial crisis	GFC
High quality liquid assets	HQLA
Inflation targeting	IT
Inflation targeting under commitment	ITC
New Keynesian	NK
Price-level targeting	PLT
Rational expectations	RE
Zero lower bound	ZLB

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HOW TO COPE WITH THE EFFECTIVE LOWER BOUND AND A LOW NEUTRAL RATE: A COMPARISON OF ALTERNATIVE MONETARY POLICY STRATEGIES

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Contents

1 Abstract

This dissertation studies whether inflation targeting is an idea past its sell-by date. Inflation targeting has been the monetary policy strategy adopted by the central banks of most developed economies in the last quarter of a century, but developments in recent years have cast doubts on the possibility that it will maintain its prominence in the future. The global and the sovereign debt crises on the one hand and the steady decline of the natural rate of interest on the other hand, have shown that the probability of hitting the effective lower bound (ELB) is much higher than previously thought. In the last decade, output and inflation have remained below their desired values for a long period of time, notwithstanding the efforts of central banks to provide as much stimulus as possible. A low level of the natural rate of interest increases the probability of hitting the ELB and reduces the room for manoeuvre of policies mostly based on interest rate management: a skilful steering of expectations becomes essential to restore the effectiveness of central banks' actions and in this respect inflation targeting seems lacking. There is by now a vast literature showing that inflation targeting underperforms other monetary policy strategies in steering expectations because it does not exhibit history dependence. The objective of this dissertation 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 frameworks seem able to outperform even the strategy suggested by Krugman (2009) and Blanchard *et al.* (2010), i.e. inflation targeting with a higher inflation objective. Robustness checks are made in order to assess whether the ranking of monetary policy strategies is sensitive to changes in model parameters or in the shock persistence.

2 Challenges for monetary policy

The global financial crisis has led central bankers to rethink how monetary policy should be conducted and implemented. 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 equaling 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 (GFC). Even if the measurement of the natural interest rate is very challenging, a sizable decline in many advanced economies has been proved by a lot of researches, using different methodologies. According to the estimates of Laubach and Williams (2016), the US natural rate of interest, which was about 2% before the crisis, 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):

1. demographic developments such as lower fertility rates, longer life-expectancy and increase in the dependency ratio 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, put downward pressure on the neutral rate;

3. the global saving glut, i.e. an excess of savings in particular by 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 preference 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 driver instead affects both the savings and investment curve.

These different sources of the decline in the interest rate could be overlapping in explaining the fall in the natural rate of interest. Predicting the future path of the natural rate of interest 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 target 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 or tightness. In G7-economies the correlation between

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

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. This happened during the GFC because, in spite of a very high unemployment rate, inflation did not plummet. For this reason, many economists recently have been debating whether the curve has disappeared in the US and Europe. Ball and Mazumder (2011), – who were among the firsts to study US inflation dynamics during the GFC, – found that the slope of the Phillips curve co-moved closely with the level and variance of inflation: it was steep when inflation was higher (in the 1970s) and it became much flatter when inflation was low and stable (around the 90s). This finding seems to be in line with Ball, Mankiw and Romer (1988). In the presence of costly nominal price adjustments, firms adjust prices more frequently for high levels of inflation, making the aggregate price level more flexible and steepening the slope of the Phillips curve. Thus, according to the Ball and Mazumder, the high degree of nominal price stickiness, coupled with low inflation, is the main reasons for which the Phillips curve has flattened.

Blanchard *et al.* (2015), who estimated for 20 advanced economies an accelerationist Phillips curve over the past 50 years, also confirmed that the slope of the Phillips curve has substantially declined from the beginning of the sample but is still statistically different from zero for 15 countries: the flattening started around the mid-1970s and stopped in the early 1990s. Some scholars deem that successful monetary policy in the ”inflation targeting era” has led to the flattening of the Phillips curve. During this period inflation has generally been lower, less volatile and anchored to the stated inflation targets (Laxton and N'Diaye 2002, Kiley 2008 and Boivin, Kiley and Mishkin 2010). Other academics find an explanations 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. Gordon (2013), for instance, argued that in some exceptional case, a flatter curve might prevent the calculation of the NAIRU, leaving central bankers ”steering the economy in a fog with no navigational device to determine the size of the unemployment gap”. 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 proved to be very successful since its introduction in the 1990s, when inflation was high and volatile, nowadays it is facing 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 kept inflation consistently below target for long.

3 Literature review

As suggested in the previous section, the likelihood of hitting the zero lower bound is much higher than previously thought, mostly because of the decline in the natural rate of interest. One important implication is that 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) as it is, is the right way to go. There seem to be two different schools of thought on the matter: evolution or revolution. The first argues for changes in the present monetary policy framework, suggesting in particular 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 an inflation targeting regime.

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 in the research literature.

Ball (2013) – estimating 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 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. This 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 an 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, 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 proposal 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 the 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 original value. This generates a higher variability in inflation than under IT and it also entails a higher output variability if nominal rigidities are presents. Svensson instead proved that in a backward-looking New Classical model satisfying certain conditions, it was indeed possible to improve inflation variability without worsening output variability. According to Svensson's results, if the model displays significant output persistence, then PLT uniformly dominates IT under discretion by improving the trade-off between inflation and output gap variability. PLT is superior even when judged on the basis of a loss function depending 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.

Vestin subsequently tested these findings in a forward-looking New Keynesian model. In Vestin's paper 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". The IT commitment solution is here taken as a benchmark to evaluate the two alternative policy regimes (IT under discretion and PLT).

In Vestin's findings, 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 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, for example, states that policy under commitment is optimal because it entails history dependence "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 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 instead 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.

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 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, in the sense that it exhibits some degree of history dependence and it is sufficiently similar to the current policy framework. They found that such a strategy may outperform both price-level targeting and inflation targeting in a model where price setters' behaviour is relatively backward-looking.

Nessén and Vestin (2005) 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 the average of inflation, measured over a given horizon, on target. This implies that AIT displays history dependence, even if in a lower degree with respect to PLT.

Vestin (2000) proved that in a forward-looking model PLT is superior to inflation targeting (IT). Nessén and Vestin (2005) extended his analysis to include average inflation targeting and seeked to assess how it measures 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 and conclusions

The research question I attempt to answer in my thesis is which 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).

I present a New Keynesian model in order to assess the effectiveness under discretion of a few different monetary policy strategies: i) inflation targeting, ii) price-level targeting and average inflation targeting. 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 some cases, 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 either normal times or when monetary policy is constrained by the zero lower bound.

The current literature finds that under discretion price level targeting is superior to inflation targeting in the following cases: 1) in a backward-looking New Classical model with significant output persistence ($\rho > 0$); 2) in a forward-looking New Keynesian model, in particular, when there is no persistence in the cost-push shock, as in that case PLT replicates the equilibrium achieved by IT under commitment.

I will try and assess whether the superiority of PLT over the current IT regime holds in a new Keynesian model in which endogenous persistence is present in the Phillips and IS curves. I also consider average inflation targeting, as in some cases it might outperform PLT since it exhibits backward-looking elements implying some degree of history dependence. Additionally, I will assess the effectiveness of an IT strategy with a higher inflation objective, which may be particularly appropriate to deal with the increasing threat of ZLB episodes.

For the evaluation of each strategy, I use a three-variable New Keynesian model in which households optimise utility (which generates the dynamic 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 deviation from target of both inflation (or the price level) and the output gap, subject to the constraint provided by the Phillips curve.

The comparison between the alternative monetary regimes (i. the current IT regime; ii. IT with a higher inflation objective; iii. PLT; iv. an average inflation targeting framework) is done by means of stochastic simulations: I generate 1000 replications for 200 periods (i.e. 40 years) and calculate for each policy framework the overall frequency 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, I calculate the variability of endogenous variables (inflation, output gap and interest rate) and the efficiency policy frontier for all strategies.

The model is estimated on euro-area data and assumes a natural rate of at most 1%; the efficiency of each strategy in achieving policy objectives *in normal times* is measured by a loss function which represents society's preferences[2]. Model simulations generate the following ranking - from best to worst - among strategies:

1. IT under commitment;
2. PLT under discretion;
3. AIT (average taken over 3 years);
4. AIT (average taken over 2 years);
5. IT (under discretion), regardless of whether the inflation target is 2% or 4%.

Although model simulations generate this ordering and 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 captured neither by the features of the model nor by the design of the simulations.

Tab. 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

The performance at the ZLB is shown for each strategy in Table 2. 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: a higher inflation objective (4%) and the two specifications of the j-period average inflation targeting (j = 8 and j = 12) substantially reduce the probability of hitting the ZLB, which falls to 8.16% in

[2]The value of the loss function in each regime, along with the variability of inflation, output gap and interest rate, is shown in Table 1.

the former case and to 10.97% or 9.11% in the latter. Surprisingly, the worse performance in terms of reducing the probability of hitting the ZLB is achieved by price-level targeting, with a ZLB incidence of 22.93%, though this result is not valid in general but is strictly linked to a high degree of inertia of the IS curve . The apparent superiority of a higher inflation objective is largely due to the inability of the three-equation New Keynesian model to account for the costs of raising the inflation target: it is not unlikely that a risk-averse policymaker might prefer a slightly higher probability of hitting the ZLB rather than bearing the unknown credibility costs of reneging its commitment to a 2% inflation objective.

Tab. 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

With endogenous persistence in the model, in normal times PLT is still superior to any other strategy, but its performance at the ZLB is disappointing. 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.

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 specifications 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.

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 effectively the transition to the ”New Normal” of monetary policy.

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 bear the potentially very significant costs of a higher inflation objective. Finally, it is the only alternative among those analysed which has been actually adopted by at least a central bank of a developed country, the Bank of Australia.

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