In search of an appropriate lower bound.
The zero lower bound vs. the positive lower bound under discretion and commitment

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Abstract

We lay the groundwork for a simple comparison of positive and possible side (adverse) effects of zero interest rate policy (ZLB policy) on welfare. Thus far, the effects of these two types have been analysed in complete isolation. Using a standard New Keynesian dynamic stochastic general equilibrium model, we show that if one assumes that the ZLB policy has no side effects (such as strengthened post-crisis financial frictions, delayed restructuring or heightened uncertainty), this policy is welfare enhancing relative to positive lower bound (PLB) policy except for the case where PLB policy is pursued under commitment, while the ZLB policy is discretionary. However, moderate side effects of the ZLB policy usually suffice for the PLB policy to pay off in terms of welfare. This is true especially when central banks fail to commit. Only if the ZLB policy is pursued under commitment and the PLB policy is discretionary does the PLB policy dominance over the ZLB policy in terms of welfare require strong side effects from the ZLB policy. Otherwise, the PLB policy could dominate the ZLB policy in terms of welfare, even if restructuring, fostered by the PLB policy, entailed costs, which could be reduced (or avoided) through slow restructuring. For given side effects of the ZLB, the larger and more persistent the shock that makes the ZLB bind, the more likely the dominance of PLB policy over ZLB policy. The findings hold for economies with both fast and slow potential output growth and low and high inflation targets, both flexible and rigid. The main findings are fairly robust to changes in the definition of shock that makes the ZLB bind.

Keywords: zero lower bound, positive lower bound, restructuring, uncertainty, discretion, commitment

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1. Introduction

Until recently, an effective lower bound on the interest rate was 2% or more (for details, see Homer and Sylla, 2005). In the 20th century, interest rates were kept below this bound only after the Great Depression, during war economies and their withdrawal, occasionally in some centrally planned economies, in Switzerland as it coped with excessive capital inflows in 1977-1978 and 1996-1999 and in Japan after the bursting of the speculative bubble at the beginning of the 1990s. The experience of Japan, where interest rates have remained below 2% since 1993 and below 0.5% since 1995, has attracted the attention of many economists to the zero lower bound (ZLB). Since Eggertsson and Woodford (2003)[1], the topic has been studied mostly through the lens of New Keynesian (NK) dynamic stochastic general equilibrium models, which eventually became the basic analytical tool for central banks. The NK analytical framework implies that the ZLB is not necessarily a serious constraint on the ability of central banks to stabilize the economy. In fact, if a central bank is highly credible, the costs of the ZLB are, according to the NK framework, quite limited. The central bank can still stabilize the economy by influencing expectations of future interest rates and inflation (see, e.g., Walsh, 2009, and the papers that Walsh refers to). However, after the collapse of Lehman in 2008, when the ZLB became binding in every major economy, their economic performance turned out to be poorer than expected (see Figure 1).

(Figure 1)

Most economists link this disappointing performance either to factors beyond the reach of monetary policy or to central banks' reluctance to rigorously follow the prescriptions of the NK framework (see, e.g., Eggertsson and Krugman, 2012; Gali et al., 2012; Mian and Sufi, 2011; Stock and Watson, 2012; Summers, 2014 or Woodford, 2012). For example, Woodford (2012) argues that although central banks shifted aggressively to interest rates close to zero, their forward guidance has provided forecasts of likely interest rate paths instead of making the commitment not to respond promptly to future demand pressure.[2] Without such a commitment, forward guidance could instil the belief in the public that growth prospects are poor.

However, few economists warn against a monetary policy that is extremely accommodative by historical standards. For example, BIS (2010, 2012, 2013, 2014) claims that such a policy can promote forbearance lending, which keeps unproductive firms afloat, crowds viable firms out of credit, and thwarts capital and labour reallocation. It thus strengthens financial frictions and deters post-crisis restructuring. In turn, Meltzer (2014) and Taylor (2014), among others, contend that the unprecedented nature of monetary policy (and other kinds of policy), its unpredictability and failure to follow rules can persistently heighten uncertainty, which invites economic agents to defer more serious adjustments.[3]

Some evidence supports the minority view. In particular, although recovery of the US economy has been sluggish by historical standards, the utilization of labour and capital has been growing faster than over previous recoveries. In contrast, growth in productivity and, above all, in capital stock (in spite of the rapid development of the capital-intensive shale gas and oil

1 For the first time, the ZLB was analysed through the lens of the NK model by Jung and his co-authors in a Hitotsubashi University working paper in 2001. The modified version of the paper was published as Jung et al. (2005).
2 Using the taxonomy set forth by Campbell et al. (2012), the forward guidance was more of a Delphic than an Odyssean nature.
3 We leave aside the most frequent criticism of extremely accommodative monetary policy, centred on risk misjudgement, excessive risk taking, and asset bubble creation (see, e.g. Adrian and Shin, 2010 and 2014; Altunbas et al., 2014; Bordo and Landon-Lane, 2013; Borio and White, 2003;Borio and Zhu, 2012; Diamond and Rajan, 2009; Farhi and Tirole, 2012; Issing, 2012, Jarocinski and Smets, 2008; Jiménez et al., 2012 and 2014 Maddaloni and Peydró, 2013, Rajan, 2005; Taylor, 2009 or White, 2010), not to mention inflationary pressure. This criticism refers to an economy that has no slack rather than to one hit by a crisis and struggling to recover, which is the focus of interest in this paper

industry) has been very slow compared to previous recoveries (see Figure 2).[4] Interestingly, the current recovery has two features in common with two previous recoveries. First, all these recoveries were preceded by interest rates being cut to a lower level than in the previous easing cycle. During the penultimate one interest rates were below 2%, like during the current one. Second, each of them proved to be more sluggish than the previous one. Moreover, the penultimate one was also accompanied by a weak growth in productivity. The weakening resulted from a deceleration of productivity growth in technological laggards while productivity growth within firms at the technological frontier remained robust (cf. Andrews et al., 2015).

(Figure 2)

Proponents of the majority view do not challenge the deficiency of restructuring after the global financial crisis.[5] They underscore that it implies no major change in the natural unemployment rate, which given that unemployment has been persistently above its pre-crisis rate, justifies a very accommodative monetary policy stance. Furthermore, some of them evoke what they call inverse Say's Law. It follows that 'lack of demand creates lack of supply potential' as firms have no reason to invest in any type of capital (Summers, 2015). It is of note, however, that stagnant productivity during the current recovery is in stark contrast to the US experience of the late 1930s, which was first labelled as 'secular stagnation' (Hansen, 1939). Although the interest rate was then close to zero as well, it could not delay post-crisis restructuring for two reasons. First, the interest rate was cut below 2% late, that is, after GDP had finally stopped falling (cf. Homer and Sylla, 2005, Ch. 17). Second, the interest rate of close to zero applied only to a small fraction of banks allowed to participate in operations with the Fed. Its effects were additionally limited by the stigmatizing nature of liquidity support from the Fed. For both reasons, having the interest rate close to zero could not promote forbearance lending, which largely conditions its adverse effect on post-crisis restructuring,

It is scarcely possible to determine unequivocally which of the two opposite views is correct. Such a settlement is certainly beyond the scope of this paper, which addresses a much less ambitious problem: how strong (weak) the possible side effects of holding interest rates close to zero have to be so that setting an effective lower bound at a higher level (and avoiding those effects) would pay off in terms of welfare.

This evaluation is based on the approach developed by Jung et al. (2005), which we generalize in two ways. First, we allow the lower bound to be any real number, not only zero.[6] As the baseline case, we consider PLB at 2%.[7] This was the floor for the policy rate of the Bank of England since its foundation in 1694 until 2009 (see Figure 3). Second, we allow for trend inflation. In the baseline case, it is set at 2%. This level matches the inflation target most frequently seen in advanced economies (see Figure 4). Moreover, it implies a real interest rate at the PLB similar to that considered in the literature on the ZLB.

(Figure 3)

[4] TFP growth was rapid in the acute phase of the global financial crisis, that is, the fourth quarter 2008 and the first quarter 2009. However, since the end of the Great Recession, i.e., the second quarter 2009 as dated by the NBER, productivity has been almost flat, with a cumulative increase until the end of 2014 of a mere 1.3% (cf. Fernald, 2014).

[5] The lack of a serious difference of opinion on the scope of restructuring after the global financial crisis between the two opposing views is exemplified by the following quotation from Bernanke (2012, p. 16): "although the recent recession was unusually deep, I see little evidence of substantial structural change in recent years."

[6] Since Gesell (1916), it has been known that the ZLB can be breached. In fact, central banks in Denmark, Eurozone, Sweden and Switzerland have reduced in recent years their policy rates to negative values, and Bank of England was seriously considering such a move in 2013. The framework that we present in this paper can easily be adjusted to analyze effects of negative lower bound. However, we leave this topic for future research.

[7] Simulations for other PLB values for the range from 0 to 2% are available upon request. We do not report them, as they have no impact (qualitatively) on the conclusions drawn.

(Figure 4)

The rationale for the second generalization relates to the fact that raising the inflation target has been promulgated to alleviate the problem of the ZLB (see, e.g., Blanchard et al., 2010). Hence, we want to observe the extent to which various inflation target values can alter the findings on the size of ZLB policy side effects that is required for setting PLB to pay off in terms of welfare.

We choose the approach developed by Jung and his co-authors because it models the expiration of shock that makes the lower bound bind in a way that can be easily linked with various narratives on side effects of interest rates close to zero (see below). However, we are aware of the shortcomings of this approach. The most serious one is that it implies that the period of time during which the lower bound binds is known (with certitude) upon the impact of the shock. This shortcoming can be addressed using the approach developed by Eggertsson and Woodford (2003). We apply this alternative approach as a robustness check of the main findings from the former approach.

The evaluation comprises two steps. First, the effects of positive lower bound (PLB) policy are studied and compared to those of ZLB policy. Four possible combinations of these polices are under scrutiny, i.e.,

(a) both PLB and ZLB policies are discretionary,
(b) both are pursued under commitment,
(c) PLB policy is pursued under commitment, while ZLB is discretionary,
(d) PLB policy is discretionary, whereas ZLB is pursued under commitment.

We use the definition of discretion and commitment by Adam and Billi (2007) and Jung et al. (2005), respectively. Second, we check how much less persistent a shock under PLB policy would have to be – compared to one dealt under ZLB policy – so that the welfare losses under the PLB did not exceed those incurred under the ZLB.

The rationale for approximating the possible side (adverse) effects of the ZLB policy by an increase in inertia of the shock to the natural interest rate is the following. There are three main types of these effects:

- forbearance lending, which strengthens the financial frictions related to collateral constraints and capital requirements;
- delays in restructuring, which postpone recovery of potential output, and
- heightened uncertainty.

All of them appear, indirectly or even directly, in the equation of the natural interest rate and can inhibit its return after a shock to the steady state (see Diagram 1).

(Diagram 1)

The NK model has been criticized for its alleged inability to analyse post-crisis reality, which is characterized by strong financial frictions, a need for restructuring, and heightened uncertainty.[8] We show that this criticism has been excessive. It is true that financial frictions have been introduced into the NK model only after the outbreak of the global financial crisis, the framework does not model restructuring and accounts for uncertainty in a very imperfect way at best. Consequently, careful study of the possible side effects of accommodative monetary policy would indeed require other tools. However, the NK model makes it possible to assess how strongly (weakly) these effects would have to differ across various policy

[8] The NK model has also been criticized for its failure to predict the global financial crisis. See, in particular, Wieland and Wolters (2011), who show that it would not have helped to predict any of the previous four recessions in the United States (in 1980, 1980-81, 1990-91 and 2001) either. In this case, we cannot help but notice that as indicated by those authors, other models were no better than the NK model on that score and underperform it in predicting recoveries.

responses to crisis to offset the differences in impact of these responses on aggregate demand. Hence, it helps to establish a weight that academics and policy makers should attach to the possible side effects of very accommodative monetary policy in their research and in their struggle to maximize social welfare, respectively. This is the goal of this paper.

Even though a medium-scale NK model, with very rich dynamics, has been developed elsewhere (see, e.g., Smets and Wouters, 2007), we use a small-scale NK model for two reasons. First, this is the first study that compares the effects of the PLB with those of the ZLB. Thus, it is reasonable to provide results as comparable as possible to previous research on the ZLB, which in the vast majority of cases is based on NK models with output gap, inflation, natural interest rate and interest rate only. Second, the extension (by this paper) of an otherwise benchmark model to allow trend inflation complicates computations, whereas it does not significantly affect the results of the comparison. This leads us to the conjecture that a focus on a medium-scale NK model would not alter them either, but it would make the computations even more complex. We leave the verification of this for further research. Even if it is refuted, gradual extension of the framework would facilitate understanding of where possible significant differences in the effects of the PLB and ZLB stem from. This would hardly be possible to verify otherwise.

Our calibration strategy is also ancillary so that the model (and results) are as comparable as possible to previous papers. Thus, we take the parameter values from those papers, but we then check the robustness of the results to changes in parameter values.

Our main findings are as follows.

First, if the ZLB policy has no side effects, such a policy is better in terms of welfare in comparison with the PLB policy unless the PLB policy is pursued under commitment, while the ZLB policy is discretionary. Put differently, commitment may matter more than the value of the effective lower bound (provided that this value remains reasonably low).

Second, as long as the central bank's ability to commit does not depend on the value of the lower bound, moderate side effects could be enough for the PLB policy to pay off in terms of welfare. This is particularly true when the central bank fails to commit (and welfare losses are large irrespective of the value of the effective lower bound).

Third, the side effects of the ZLB would have to be strong for the PLB policy to outperform the ZLB policy in terms of welfare only if the ZLB policy was pursued under the commitment, while the PLB policy was discretionary. In other words, the commitment could weigh on welfare more than the possible side effects of the ZLB, mainly, however, under the condition that it would be more likely under the ZLB policy than the PLB policy.

Fourth, when the above condition is not met, PLB policy could dominate the ZLB policy in terms of welfare, even if restructuring, fostered by the PLB policy, entailed some costs, which could be reduced (or avoided) through slow restructuring.

Sixth, with the given side effects of the ZLB policy, PLB policy is more likely to be welfare improving compared to ZLB policy when a shock that makes the ZLB bind is particularly large and persistent. This result implies that the central bank should be particularly cautious about cutting interest rates to zero in circumstances where other papers consider calling for aggressive cuts.

Seventh, the above findings hold for economies with both fast and slow potential output growth, with low and high inflation targets, both flexible and rigid. Any differences in the results between these economies are small, but if anything, they advocate for more cautiousness about cutting interest rates to zero in countries with slow potential output growth, low inflation targets, and strong rigidities – nominal and in the labour supply, although more fierce competition.

Eight, the main findings hold when the definition of a shock proposed by Eggertsson and Woodford (2003) is applied. Specifically, it follows from this alternative approach that when a central bank fails to commit, quite moderate side effects of ZLB policy are enough for PLB policy to outperform ZLB policy in terms of welfare. If, on the contrary, a central bank successfully commits, this commitment weighs more on welfare than the exact value of the effective lower bound (as long as this value is reasonably low). Commitment is so important for welfare that if its credibility were contingent on cutting interest rates to zero, it would justify running ZLB policy in spite of the possible side effects of such a policy.

The paper makes four main contributions to the literature.

First, it studies the effects of the PLB. The possibility of a positive lower bound instead of being zero has been observed in other studies on ZLB.[9] However, it has only been analysed, if at all, in the context of a 'lack of confidence' shock and self-fulfilling deflation (see, e.g., Benhabib et al., 2001; Schmitt-Grohé and Uribe, 2010 or Schmitt-Grohé and Uribe, 2012). We analyse the 'fundamental' shock instead, which is extensively used in the literature on ZLB.

Second, the paper develops a simple analytical framework that makes it possible to compare benefits with the possible costs of an interest rate close to zero. Thus far, both of these effects have been analysed in complete isolation from each other. We break this isolation and thereby better exploit the knowledge acquired from the above analyses.

Third, this paper puts into question an important piece of policy advice from the literature on the ZLB. Since Eggertsson and Woodford (2003), the literature has unanimously advocated for aggressive interest rate cuts in response to severe negative shocks or the anticipation thereof. Our findings suggest, instead, that the more severe a shock, the more cautious the central bank should be about cutting interest rates to zero. The main reason for this caution is the risk of side effects from the ZLB policy, whereas in older papers, it is to preserve dry powder for future emergencies.

Fourth, the paper highlights the significance of the central bank's credibility from a different perspective than other studies on ZLB. They consider credibility as a condition for a central bank's ability to stabilize the economy when the ZLB binds. We add that a central bank has strong reasons to cut interest rates to zero only if such cuts are a condition for its credibility.

The remainder of the paper is organized in four sections and an appendix. Section 2 reviews the related literature and sets forth the context of the analysis. Its primary goal is to elaborate on why possible side effects of the ZLB policy can be approximated in the NK analytical framework by an increase in inertia of the shock to the natural interest rate. Section 3 describes the model used and its calibration. Section 4 provides the main findings and verifies their robustness as well as briefly discusses their policy implications. Section 5 concludes. The appendix, including figures and tables, follows.

2. Related literature and context

Our findings relate to the strand of the literature on the ZLB that envisages a 'fundamental' shock using the NK analytical framework. Leading examples of such research include Adam and Billi (2006 and 2007), Eggertsson (2003 and 2006), Eggertsson and Woodford (2003), Jung et al. (2005), Levin et al. (2010), Nakov (2008) or Walsh (2009). In this literature, a severe shock, which is usually a preference shock, hits the natural interest rate r_t. Literally interpreted, this means that suddenly everyone wants to save more. However, given that the natural interest rate may also depend on other variables than the discount factor, more sophisticated interpretations are also possible, and indeed they are used. In particular, there have been recent references to financial frictions (cf., e.g., Eggertsson, 2011). Although financial frictions are not modelled in the versions of the NK framework commonly used in analyses of the ZLB, it

9 Obviously, papers warning against very accommodative monetary policy not only note the possibility of the lower bound being positive but postulate its value. However, they do not analyse its effects using the NK analytical framework, even if some of the papers refer to this framework (see Ciżkowicz and Rzońca, 2014).

has been shown elsewhere that NK models that incorporate them can be reduced to a form quite similar to the standard version (see, e.g., Christiano et al., 2011), with modified natural interest rate $\tilde{r}_t$ defined as follows:

$$\tilde{r}_t = r_t - \sigma \psi_t \tag{1}$$

where ψ_t is a measure of financial friction (and σ is the parameter of relative risk aversion of households). Our analysis uses this latter interpretation.

Our findings also relate to the literature on the possible side effects of very accommodative monetary policy (see, in particular, BIS, 2010, 2012, 2013, 2014). It draws first and foremost from the experience of Japan in the 1990s and 2000s, that is, from the very same experience that renewed the interest of economists in the ZLB. After the asset bubble burst in the early 1990s, troubled Japanese banks allocated scarce credit to impaired, debt-ridden firms rather than to viable ones. However, credit flowing to otherwise insolvent firms did not improve their performance (Peek and Rosengren, 2005). On the contrary, their poor financial conditions worsened further (Sekine et al., 2003). Banks imposed discipline on viable firms only (Arikawa and Miyajima, 2007). Insolvent firms that were kept afloat lowered viable firms' profitability, which discouraged their development and the entry of new firms (Caballero et al., 2008). Still worse, while support for non-viable firms was maintained, many productive firms, especially new entrants, exited (Nishimura et al., 2005). In industries with a heavy presence of non-viable firms, they increased their market share (Ahearne and Shinada, 2005). Payment uncertainty discouraged specialization (Kobayashi, 2007). Technology spill-overs declined (Fukao, 2013). Political leadership resisted capital and labour reallocation as well. A significantly softened budget constraint enabled government to delay necessary adjustments (Dugger and Ubide, 2004). Good lending opportunities for solvent banks diminished (Caballero et al., 2008). Information effectiveness of the asset markets decreased (Hamao et al., 2007). In summary, distortions in capital and labour reallocation increased and prolonged the disappointing economic performance of Japan (Nishimura et al, 2005).

Although the literature in question has been developed outside of mainstream economics, it is likely to bring relevant policy lessons. It argues that qualitatively similar distortions to those in Japan have appeared in other major economies after the outburst of the global financial crisis. Evidence of forbearance lending was found in Italy (Albertazzi and Marchetti, 2010) and the UK (Arrowsmith et al., 2014). Although in the UK it was of limited scale, corporate insolvencies remained historically low there, while in the early phases of previous recoveries they had spiked (R3, 2013). At the same time, the share of firms suffering losses exceeded 30%, reaching the highest level since at least the 1980s (Deutsche Bank, 2013). Because firms of low productivity continued to operate in spite of being on the brink of insolvency, differences in productivity across firms became wider than ever. The contribution of reallocation to productivity growth fell during the crisis and became almost negligible in 2010-2012, whereas it had accounted for more than two-thirds of productivity growth prior to the crisis. Correlation between profitability and investment across firms weakened considerably. The share of both product and process innovators decreased (Barnett et al., 2014a and 2014b). In the US, the increase in insolvencies after the outburst of the crisis was very short-lived (Deutsche Bank, 2013). Churn decreased significantly (Lazear and Spletzer, 2012), as well as the number of startups, even in high-tech industries (Davis and Haltiwanger, 2014). Reallocation not only became less intensive but also enhanced productivity less than over previous recessions (Foster et al., 2014). Both in Europe and the US, central banks' interventions distorted asset prices and, thereby, weakened market signals (Borio, 2014).

Cross-country comparisons of post-crisis economic performance also suggest that possible side effects of a very accommodative monetary policy should not be neglected. Bech et al. (2014) find that the benefits of such a policy during a downturn for a subsequent recovery disappear if the downturn follows a financial crisis. At the same time, the deeper the private sector deleveraging during a downturn, the stronger the subsequent recovery. Kannan et al. (2013) confirm that accommodative monetary policy is of limited effectiveness in advancing a recovery after a financial crisis. In turn, Chen et al (2015) corroborate that the larger and the quicker the private sector deleveraging, the more sizable the medium-term output gains. In line with these results, Laeven and Valencia (2013) find that advanced economies, which relied on macroeconomic policies as crisis-management tools more heavily than emerging economies, were much slower to resolve banking crises, which lasted on average two times longer than in emerging economies. It follows from the study that, while accommodative macroeconomic policies help to avoid disorderly deleveraging, they can also weaken incentives for financial restructuring, with the risk of entrenching weak economic performance.

It is possible to put an end to the isolation that exists between the literature on the ZLB and the possible side effects of very accommodative monetary policy because the main types of these effects, namely, forbearance lending, delayed restructuring and heightened uncertainty, appear, indirectly or even directly, in the natural interest rate equation that is at the centre of the literature on the ZLB (recall the Diagram 1).

Forbearance lending, facilitated by ZLB policy, can be considered to inhibit the return of the natural interest rate to the steady state because it strengthens financial frictions (see Eq. 1) related to collateral constraints and capital requirements.[10] First, it distorts publicly available signals that help to assess the financial credibility of firms and expands the range of information required for such an assessment. As non-viable borrowers are able to demonstrate positive credit history, viable firms have to manifest their credibility in ways other than by being monitored by banks. They can differentiate themselves from non-viable firms by deleveraging, as the non-viable firms are scarcely able to deleverage, but this perverse composition of deleveraging firms magnifies problems of information asymmetry. Second, forbearance lending forces banks to rely heavily on retained earnings to rebuild their capital. This reduces their valuation, for it exposes potential investors to the burden of undisclosed losses from the past and reduces expected profits from future operations until the entire banking sector undergoes restructuring. Hence, the rebuilding of capital takes a long time (additionally prolonged by the compression of banks' interest margin). Capital-constrained banks cannot offer new credit to viable firms. Note that the very limited access of banks to new capital strengthens, in turn, their incentive to delay balance sheet repair, as this delay helps them to meet capital requirements.

A decelerated return of the natural interest rate to the steady state can also be associated with delays in restructuring that the ZLB policy can cause. It suffices to assume that restructuring drives productivity growth or, more generally, potential output growth (see Eq. 2).

$$r_t = \sigma(y_{t+1}^P - y_t^P) + (1-\beta)/\beta \tag{2}$$

where β is the household's subjective discount factor and $y_{t+1}^P - y_t^P$ is the growth rate of potential output. This assumption is confirmed in numerous studies (for more, see Caballero, 2007).

The ZLB policy can hamper restructuring, in particular through forbearance lending. First, forbearance directs credit to the present borrowers, which reduces the exit of enterprises instead of promoting entry. Second, it supports current operations instead of new ones, which could increase the productivity of firms continuing operations. Firms in receipt of forbearance have no incentive to restructure because the effort put into restructuring would bring benefits to their creditors, not to them. Furthermore, they have to avoid any additional expenses (which restructuring usually requires for some time), as new costs could be considered by banks a signal of actions that increase creditors' losses and thus could result in an immediate cut off

10 Collateral constraints and capital requirements represent two out of three of the main types of financial frictions that started to be introduced into the NK analytical framework after the outbreak of the global financial crisis (see, e.g., Andrés and Arce, 2009 and Angeloni and Faia, 2013).

from funding. This inspires inaction and leads to betting for resurrection. Third, forbearance lending hinders an increase in the market share of most productive businesses, as it helps non-viable firms while pushing viable firms to deleverage (see Eq. 3).

$$y_t^P - y_{t-1}^P = s_{t-1}^X\left(a_t^E - a_{t-1}^X\right) + s_{t-1}^I \Delta a_t^I + \left(\left(s_t^E - s_{t-1}^X\right)a_t^E + \Delta s_t^I a_t^I\right) \quad (3)$$

where a is the logarithm of productivity in a given set of firms, s is the share of a given set of firms in output, and the E, I, X superscripts indicate the set of firms entering the market, the set of firms continuing operation, and the set of firms exiting the market, respectively. Note, however, that even if only a few non-viable firms were in receipt of forbearance, a deep fall in interest payments could have quite similar effects to those of forbearance, for it facilitates non-viable firms to look solvent and banks to delay loss recognition and balance sheet repair (cf. Arrowsmith et al., 2014).[11] Very accommodative monetary policy can also discourage government from reforms that enhance restructuring (Borio, 2014).

It is of note that attempts to explain persistently low estimates of r_t in the United States since the outburst of the global financial crisis associate them largely with a decline in $y_{t+1}^P - y_t^P$ (see Pescatori and Turunen, 2015 or Williams, 2015).

Ultimately, one can consider heightened post-crisis uncertainty prolonged by the ZLB policy to be responsible for the slower return of the natural interest rate to the steady state (see Eq. 4)[12].

$$\hat{r}_t = r_t - \frac{1}{2}\sigma^2 \operatorname{var}_t(y_t^P) \quad (4)$$

By delaying post-crisis adjustments, the ZLB policy maintains uncertainty about timing, scope, and the effects of restructuring while narrowing the possibilities for reducing uncertainty through information acquisition and processing, as its quality is low.[13] At the same time, there is a high risk that the newly acquired information will soon become obsolete. Even a small negative shock may cease the operations of non-viable firm, for banks may confound the effects of shock with debtor's actions, increasing their losses. Worse, a positive economic development is not at all favourable for such firms either because it increases the risk that banks stop forbearance lending, and the firm loses funding. The more non-viable firms there are, the more uncertain a positive economic development becomes for other firms, as their important partners may prove to be non-viable or may collaborate with non-viable firms. All in all, firms do not know when the structure of the economy will seriously change or how it will change. However, they should have no doubt that serious changes will occur. If the economy had not needed them, there would have been no crisis. The unprecedented nature of the ZLB policy contributes to that risk, as indicated in the introduction.

Therefore, we approximate the possible side effects of ZLB policy as an increase in inertia of a shock to the natural interest rate.

Technically, one may reach this approximation as follows. Let ϵ_t be a shock to the natural interest rate with inertia parameter ρ. In period 1, ϵ_1 hits the economy and makes the ZLB bind. In period 2, it starts to expire. However, if side effects of the ZLB policy materialize, another shock ϵ_2^{ZLB}occurs. This shock reflects financial frictions strengthened by forbearance lending, productivity growth muted by delays in restructuring or uncertainty heightened by these delays. Its dynamics are hard to specify. In particular, forbearance lending can be quite limited in the periods very close to period 1 and become widespread only later given that it is

11 It is sometimes noted in favour of forbearance that it helped banks in advanced economies, particularly in the US, to overcome solvency problems caused by defaults of a number of developing countries in the early 1980s. However, that forbearance was targeted and conditional, while a deep fall in interest payments due to an interest rate close to zero resembles general and open-ended forbearance.

12 We take this relationship from Barsky et al. (2014). It is generally neglected for two interrelated reasons. First, until recently, only the first-order Taylor expansion of the model has been considered. Second, it is usually assumed that the second-order terms are small (see, e.g. Gali, 2008).

13 Non-viable firms kept afloat hinder assessment of the financial credibility of a firm and its partners, both existing and potential.

fostered by two strategic complementarities[14], which need time to fully work. The percentage of firms delaying restructuring can change according to forbearance lending prevalence. In turn, uncertainty, although related to delays in restructuring, can increase more rapidly because it depends not only on the intensity of its given source but on its 'novelty' as well. Nevertheless, at some point, the shock ϵ_t^{ZLB} has to expire if the steady state is not to change. We calibrate this shock to keep convenient the constant inertia of the total shock to the natural interest rate:

$$\epsilon_t + \epsilon_t^{ZLB} = \epsilon_t \tilde{\rho}^{t-1} \tag{5}$$

where:

$$\begin{cases} \tilde{\rho} = \rho + \frac{\epsilon_2^{ZLB}}{\epsilon_1} > \rho \\ \tilde{\rho} < 1 \end{cases} \tag{6}$$

Note that such a calibration is consistent with the likely hump shape of the expiration of ϵ_2^{ZLB}. It also implies that ϵ_2^{ZLB} is weaker than ϵ_1, especially in the case of a large ρ. Under our baseline calibration of ρ, as specified in Table 1 (see the next section), ϵ_2^{ZLB} has to be more than five times as weak as ϵ_1 at least. The baseline calibration of ϵ_1 implies that ϵ_2^{ZLB} should amount to less than 0.66 of (quarterly) standard deviations of shock to the natural interest rate in the US, as identified by Adam and Billi (2006, 2007).

Alternatively, the approximation of possible side effects of ZLB policy may be centred on a lengthening of the expected period of reversion of the natural interest rate to the steady-state value, the lengthening that such a policy could cause if – let us reiterate – it promoted forbearance lending and thereby strengthened financial frictions, delayed post-crisis restructuring or prolonged the period of heightened uncertainty. We apply this alternative approximation as a robustness check. In this approach based on Eggertsson and Woodford (2003), ϵ_t does not exhibit an autoregressive dying-out pattern but remains at a constant level ε_1 until some unknown date T, when the natural interest rate reverts to the steady-state value. ZLB policy is thought to reduce conditional probability of this reversion, fixed at δ in each period, and as a result, to lengthen the expected period of the reversion, which is given by $1/\delta$.

3. Model description

We use in the simulations the analytical framework developed by Jung et al. (2005), which we generalize in two ways, as specified in the introduction. Namely, we allow for PLB and trend inflation in the model. Most previous research on the lower bound for interest rates was based on the standard New Keynesian Phillips Curve, which we have to modify accordingly, along with the algorithm for model solution.

3.1. The model

As in Jung et al. (2005) or Eggertsson and Woodford (2003), the central bank faces the following minimization problem:

$$\mathcal{L}_t = \sum_{i=0}^{\infty} \beta^i L_{t+i} \tag{7}$$

with the following one-period loss function L_t:

$$L_t = \pi_t^2 + \lambda y_t^2 \tag{8}$$

[14] First, a bank's willingness to keep lending to over-indebted firms depends on other banks' decisions with regard to such clients, as these decisions affect both the expected revenue of a delayed sale of insolvent debtors' assets and expected profits on credit expansion that would require a quick repair of the bank's balance sheet. Second, it also depends on over-indebted firms restraining from actions that would increase their pay-off variance and, consequently, the expected losses of the bank. The more widespread the forbearance lending, the larger the chance for such a restraint to be considered by over indebted firms as the most effective strategy to continue operations.

where y_t is the output gap at t. Note that, under trend inflation, π_t is no longer the inflation rate but deviation of the inflation rate from the steady state. This has no influence on the variance of π^2 or, as a consequence, on policy ranking according to the loss function values.

Policymakers are constrained by standard behavioural equations, i.e., the IS curve and the Phillips curve. The former is only slightly modified in a straightforward way to account for positive inflation in the steady state ($\bar{\pi}$):

$$y_t = E_t y_{t+1} - \sigma^{-1}(i_t - E_t\pi_{t+1} - \bar{\pi} - r_t) \tag{9}$$

where i_t is the nominal interest rate at t. The Phillips curve under trend inflation has been proven by multiple authors to contain additional dynamic components in comparison to its counterpart under the zero steady state[15] (see Ascari, 2004; Bakhshi et al., 2007; Cogley and Sbordone, 2008). A simple quasi-differencing operation makes it possible to present this equation in the following recursive form:

$$\pi_t = \beta_1 E_t\pi_{t+1} + \beta_2 E_t\pi_{t+2} + \kappa_1 y_t + \kappa_2 E_t y_{t+1} \tag{10}$$

whereby the reduced-form parameters in (10) are derived as follows:

$$\beta_1 = \beta\left\{(1-\theta\bar{\Pi}^{\varepsilon-1})\left[\left(\frac{\varepsilon + \dfrac{\varphi+\alpha}{1-\alpha}\varepsilon}{1+\dfrac{\varphi+\alpha}{1-\alpha}\varepsilon}\right)\bar{\Pi}^{1+\frac{\varphi+\alpha}{1-\alpha}\varepsilon} - \frac{\varepsilon-1}{1+\dfrac{\varphi+\alpha}{1-\alpha}\varepsilon}\right] + \theta\bar{\Pi}^{\varepsilon+\frac{\varphi+\alpha}{1-\alpha}\varepsilon}\right\} + \beta\theta\bar{\Pi}^{\varepsilon-1}$$

$$\beta_2 = -\theta\beta^2\bar{\Pi}^{\varepsilon+\frac{\varphi+\alpha}{1-\alpha}\varepsilon}$$

$$\kappa_1 = \frac{(1-\theta\bar{\Pi}^{\varepsilon-1})\left(1-\theta\beta\bar{\Pi}^{\varepsilon+\frac{\varphi+\alpha}{1-\alpha}\varepsilon}\right)}{\theta\bar{\Pi}^{\varepsilon-1}}\left(\frac{\dfrac{\varphi+\alpha}{1-\alpha}+\sigma}{1+\dfrac{\varphi+\alpha}{1-\alpha}\varepsilon}\right) + \frac{\beta(1-\theta\bar{\Pi}^{\varepsilon-1})\left(1-\bar{\Pi}^{1+\frac{\varphi+\alpha}{1-\alpha}\varepsilon}\right)}{1+\dfrac{\varphi+\alpha}{1-\alpha}\varepsilon}$$

$$\kappa_2 = \frac{\left(\bar{\Pi}^{1+\frac{\varphi+\alpha}{1-\alpha}\varepsilon}-1\right)\beta(1-\theta\bar{\Pi}^{\varepsilon-1})(1-\beta\theta\bar{\Pi}^{\varepsilon-1})}{1+\frac{\varphi+\alpha}{1-\alpha}\varepsilon} - \beta\theta\bar{\Pi}^{\varepsilon-1}\kappa_1 \tag{11}$$

The notation for deep parameters used in equation (11) follows full derivation of the standard New Keynesian Phillips curve in Gali (2008), i.e., β is households' subjective discount factor as in equation (2), θ is the Calvo probability, $1-\alpha$ is the Cobb-Douglas exponent on labour in the production function, φ is the Frisch elasticity of labour supply, and ε is the elasticity of substitution between goods varieties. $\bar{\Pi} = 1 + \bar{\pi}$ is the gross inflation rate in the steady state. While the previous literature on the ZLB refers to reduced-form parameters of the Phillips curve, we prefer to calibrate the structural parameters to ensure the consistency between individual reduced-form parameters in extended equation (10).

Minimizing (8) subject to constraints (9) and (10), after skipping the expectation operators (under perfect foresight, as in Jung et al., 2005), implies the following Lagrange function:

$$\begin{aligned}\mathcal{L}_t = \textstyle\sum_{i=0}^{\infty}\beta^i \quad \{&L_{t+i} + 2\phi_{1,t}[y_t - E_t y_{t+1} + \sigma^{-1}(i_t - E_t\pi_{t+1} - \bar{\pi} - r_t)] + \\ &+2\phi_{2,t}[\pi_t - \beta_1 E_t\pi_{t+1} - \beta_2 E_t\pi_{t+2} - \kappa_1 y_t - \kappa_2 E_t y_{t+1}]\}\end{aligned} \tag{12}$$

where $\phi_{1,t}$ and $\phi_{2,t}$ are Lagrange multipliers. Note that in this setup, the central bank sets i_t equal to $\bar{\pi} + r_t$ and the loss function is value zero as long as we ignore further constraints on i_t. Turning to the case of any positive lower bound for interest rates requires a modification of Kuhn-Tucker conditions related to the constraint $i_t \geq PLB$ (instead of $i_t \geq 0$), which now takes the form:

$$(i_t - PLB)\phi_{1,t} = 0 \tag{13}$$

$$i_t \geq PLB \tag{14}$$

[15] Specifically, the New Keynesian Phillips curve under trend inflation contains on the right-hand side the output gap (or real marginal cost), the expected inflation rate at a 1-period lead, but also an infinite, exponentially weighted sum of further leads of the output gap and inflation rate. Leading this equation by one period, multiplying by the ratio of two subsequent weights ($\beta\theta\bar{\Pi}^{\varepsilon-1}$) and subtracting this from, the original equation yields equation (8) after basic simplifications.

$$\phi_{1,t} \geq 0 \tag{15}$$

This implies that, as in previous analyses of the ZLB, two states are possible: The lower bound is non-binding (which implies zero loss and a zero Lagrange multiplier on the IS curve) or binding (which leads to a positive loss, i.e., non-fulfilment of equation (9) and a positive Lagrange multiplier on the IS curve).

3.2. Shock definition

We start in period 0 and assume that all variables take their steady-state values, i.e., the (net) inflation rate is equal to $\bar{\pi}$, $\bar{y} = \overline{\phi_1} = \overline{\phi_2} = 0$ and $r_t = \bar{r}$. The steady-state value of the natural interest rate can be estimated from equation (2) as in Jung et al. (2005). In period 1, as stated in section 2, a shock of size ϵ_1 occurs that brings the natural interest rate down to a level that renders the lower bound binding ($i_1 = PLB$ and $\phi_{1,1} = 0$):

$$r_1 = \bar{r} + \epsilon_1 \tag{16}$$

Recall that the shock is assumed to exhibit serial correlation of order 1 with inertia parameter ρ:

$$r_t = \rho r_{t-1} + (1-\rho)\bar{r} \tag{17}$$

Further shocks are not considered, i.e., equation (17) is valid for t=2,3,…; this dying out pattern implies that, for some $t > 1$, the lower bound will cease to bind. Further analysis depends on whether the central bank can credibly commit to the optimum rule (12), subject to (13)-(15), or acts under discretion.

3.3. Solution under commitment

When the central bank credibly commits to the optimum policy rule from t onwards, the first order conditions from the Lagrange problem (10) take the following form:

$$\lambda y_t + \phi_{1,t} - \beta^{-1}\phi_{1,t-1} - \kappa_1\phi_{2,t} - \beta^{-1}\kappa_2\phi_{2,t-1} = 0 \tag{18}$$

$$\pi_t - (\beta\sigma)^{-1}\phi_{1,t-1} + \phi_{2,t} - \beta^{-1}\beta_1\phi_{2,t-1} - \beta^{-2}\beta_2\phi_{2,t-2} = 0 \tag{19}$$

Note that the generalization to positive steady-state inflation, as in (10), implies the inclusion of second-order dynamics in the model. This also emerges in (19) as the second lag of the Lagrange multiplier ϕ_2.

The lower bound is binding from $t = 1$ to $t = T$. The last period when this constraint is binding can be found on the basis of ϕ_1; i.e., T is established so that $\phi_{1,T}$ is positive but $\phi_{1,T+1}$ is not according to conditions (13)-(15). In practice, a relatively high value of T is considered at the beginning, and it is iteratively decremented until the abovementioned condition is met.

It should perhaps be mentioned that due to the presence of second-order dynamics and the resulting overshooting patterns, the algorithm had to be slightly modified compared to, e.g., Jung et al. (2005). It is insufficient to consider a distant T and decrement it until a positive value of $\phi_{1,T}$ appears for the first time; instead, one needs to keep track of this condition coupled with another one, stating that for t=1,…,T, $\phi_{1,t} > 0$.

Accordingly, the model solution consists of the following phases:

1. Equations (9), (10), (18) and (19) for $t = 1, \ldots, T$ with $i_t = PLB$.
2. Equations (10), (18) and (19) for $t = T + 1$ with $\phi_{1,T+1} = 0$, but $\phi_{1,T} > 0$.
3. Equations (10), (18) and (19) for $t = T + 2, T + 3, \ldots$ with $\phi_{1,T+1} = 0$ and $\phi_{1,T+2} = 0$, etc.

In phases 2 and 3, i_t is additionally derived from equation (9).

Phase 1 takes as initial conditions $\phi_{1,0} = 0$, $\phi_{2,0} = 0$ and $\phi_{2,-1} = 0$. The terminal conditions for this phase are y_{T+1}, π_{T+1} and π_{T+2}.

In **Phase 3**, we use equation (18) to express y_t as a function of $\phi_{2,t}$ and $\phi_{2,t-1}$. After substitution into (10), we obtain a difference equation in π_t, π_{t+1}, π_{t+2}, $\phi_{2,t-1}$, $\phi_{2,t}$ and $\phi_{2,t+1}$. This equation, coupled with (19), forms a dynamic system of forward-looking equations that can be cast into matrix form as:

$$\boldsymbol{A}\begin{bmatrix}\pi_{t+2}\\ \pi_{t+1}\\ \phi_{2,t+1}\\ \phi_{2,t}\end{bmatrix}=\boldsymbol{B}\begin{bmatrix}\pi_{t+1}\\ \pi_{t}\\ \phi_{2,t}\\ \phi_{2,t-1}\end{bmatrix}\tag{20}$$

with $\boldsymbol{A}=\begin{bmatrix}\beta_2 & \beta_1 & \kappa_1\kappa_2\lambda^{-1} & \lambda^{-1}(\kappa_1^2+\kappa_2^2\beta^{-1})\\ 0 & 1 & 1 & -\beta_1\beta^{-1}\\ 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}$ and $\boldsymbol{B}=\begin{bmatrix}0 & 1 & 0 & -\kappa_1\kappa_2\lambda^{-1}\beta^{-1}\\ 0 & 0 & 0 & \beta_2\beta^{-2}\\ 1 & 0 & 0 & 0\\ 0 & 0 & 1 & 0\end{bmatrix}$.

This system contains 2 variables predetermined at t ($\phi_{2,t}$, $\phi_{2,t-1}$) and can be solved with Klein's (2000) method as a law of motion for these two variables:

$$\begin{bmatrix}\phi_{2,t}\\ \phi_{2,t-1}\end{bmatrix}=\begin{bmatrix}\gamma_1 & \gamma_2\\ 1 & 0\end{bmatrix}\begin{bmatrix}\phi_{2,t-1}\\ \phi_{2,t-2}\end{bmatrix}\tag{21}$$

The upper block of (21), coupled with (19) – and with the fact that all relevant lags of ϕ_1 are zero in phase 3 – yields the following system of equations:

$$\begin{bmatrix}\pi_t\\ \phi_{2,t}\end{bmatrix}=\begin{bmatrix}-\gamma_1+\beta^{-1}\beta_1 & -\gamma_2+\beta^{-2}\beta_2\\ \gamma_1 & \gamma_2\end{bmatrix}\begin{bmatrix}\phi_{2,t-1}\\ \phi_{2,t-2}\end{bmatrix}\tag{22}$$

As a result, phase 3 takes $\phi_{2,T}$ and $\phi_{2,T+1}$ as initial conditions.

Phase 2 is simulated on the basis of initial conditions on Lagrange multipliers and terminal conditions on y and π. In both cases, the system of equations can be expressed in a matrix form as:

$$\begin{bmatrix}\pi_t\\ y_t\\ \phi_{2,t}\end{bmatrix}=\boldsymbol{A_1}\begin{bmatrix}\phi_{2,t-1}\\ \phi_{2,t-2}\end{bmatrix}+\boldsymbol{A_2}\begin{bmatrix}\pi_{t+2}\\ \pi_{t+1}\\ y_{t+1}\end{bmatrix}+\boldsymbol{B_1}[\phi_{1,t}]+\boldsymbol{B_2}[\phi_{1,t-1}]\tag{23}$$

Note that for $t=T+1$, i.e., in phase 2, $\boldsymbol{B_1}$ is equal to the zero vector. Additionally, $\boldsymbol{B_2}=(\lambda+\kappa_1^2)^{-1}\begin{bmatrix}\kappa_1^2(\beta\sigma)^{-1}+\kappa_1\beta^{-1}\\ \kappa_1(\beta\sigma)^{-1}+\beta^{-1}\\ \lambda(\beta\sigma)^{-1}-\kappa_1\beta^{-1}\end{bmatrix}$, $\boldsymbol{A_1}=(\lambda+\kappa_1^2)^{-1}\begin{bmatrix}\kappa_1^2\beta^{-1}\beta_1+\kappa_1\beta^{-1}\kappa_2 & \kappa_1^2\beta^{-2}\beta_2\\ \kappa_1\beta^{-1}\beta_1+\beta^{-1}\kappa_2 & \kappa_1\beta^{-2}\beta_2\\ \lambda\beta^{-1}\beta_1-\kappa_1\beta^{-1}\kappa_2 & \lambda\beta^{-2}\beta_2\end{bmatrix}$ and $\boldsymbol{A_2}=(\lambda+\kappa_1^2)^{-1}\begin{bmatrix}\beta_2\lambda & \beta_1\lambda & \kappa_2\lambda\\ -\kappa_1\beta_2 & -\kappa_1\beta_1 & -\kappa_1\kappa_2\\ -\lambda\beta_2 & -\lambda\beta_1 & -\lambda\kappa_2\end{bmatrix}$.

3.4. Solution under discretion

The first-order conditions do not read as (18) and (19) when the central bank cannot credibly commit to the same optimum policy rule in the future. In such a case, the timing to terminate the lower bound on interest rates is exogenous to the model (as in the special case of ZLB, cf. Jung et al., 2005) and can be determined by the following rule:

$$\begin{gathered}r_T+\bar{\pi}\le PLB\\ r_{T+1}+\bar{\pi}>PLB\end{gathered}\tag{24}$$

In (24), and per the analogy to the case of commitment, T is the last period of the lower bound binding, and $T+1$ is the first period after the constraint has ceased to bind.

The solution for $t=T+1$ and later is straightforward: the central bank sets $i_t=r_t+\bar{\pi}$ to keep $y_t=\pi_t=0$.

For $t=1,\ldots,T$ the model consists of equations (9), (10), along with the constraint equation:

$$i_t=PLB\tag{25}$$

The model is completed by the terminal conditions on y and π:

$$\begin{aligned} y_{T+1} &= 0 \\ \pi_{T+1} &= 0 \\ \pi_{T+2} &= 0 \end{aligned} \tag{26}$$

3.5. Alternative shock definition and solution method

As a robustness check, we examine the effects of PLB policy with the shock definition from Eggertsson and Woodford (2003). In period 0, the economy is in the steady state, and in period 1, a shock occurs as in (16). Recall, however, that under this formulation, it remains at a constant level ε_1 until some unknown date T, when the natural rate of interest reverts to the steady-state value. Economic agents base their expectations about future developments on a conditional probability of this reversion, fixed at δ in each period.

Under commitment, the solution technique is based on Eggertsson and Woodford (2003) but modifies their approach to account for a positive rather than zero lower bound as well as for second-order dynamics of the Phillips curve arising due to non-zero inflation in the steady state. Following the notation by Eggertsson and Woodford (2003), we set $\boldsymbol{Z}_t = \begin{bmatrix} y_t \\ \pi_t \\ \pi_{t+1} \end{bmatrix}$ and $\boldsymbol{P}_t = \begin{bmatrix} \phi_{1,t} \\ \phi_{2,t} \\ \phi_{2,t-1} \end{bmatrix}$ (note the difference in the latter definition compared to Eggertsson and Woodford, 2003). The solution is split into 3 phases.

Phase 3 begins when the natural interest rate has already reverted to the steady-state value and ϕ_1 has converged from positive values to zero. Beginning with that point, the system consists of equations (18) and (22). We cast them into form from Eggertsson and Woodford (2003) as:

$$\boldsymbol{P}_t = \boldsymbol{\Omega^0} \boldsymbol{P}_{t-1} \tag{27}$$

$$\boldsymbol{Z}_t = \boldsymbol{\Lambda^0} \boldsymbol{P}_{t-1} \tag{28}$$

with $\boldsymbol{\Omega^0} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & \gamma_1 & \gamma_2 \\ 0 & 1 & 0 \end{bmatrix}$ and $\boldsymbol{\Lambda^0} = \begin{bmatrix} (\beta\lambda)^{-1} & \kappa_2(\beta\lambda)^{-1} & \kappa_1\gamma_2\lambda^{-1} \\ (\beta\sigma)^{-1} & -\gamma_1 + \beta^{-1}\beta_1 & -\gamma_2 + \beta^{-2}\beta_2 \\ 0 & (\beta^{-1}\beta_1 - \gamma_1)\gamma_1 + \beta^{-2}\beta_2 - \gamma_2 & (\beta^{-1}\beta_1 - \gamma_1)\gamma_2 \end{bmatrix}$ (note that we use here the lower block of (22) to substitute for $\phi_{2,t}$ in (18) and exploit the fact that $\phi_{1,t} = 0$ in this phase). The third row is a forward-iterated version of the second.

Phase 2 lasts from period $t = \tau$ (when the natural interest rate reverts to the steady-state value) until $t = \tau + k_\tau$ (when $\phi_{1,t}$ is no longer positive; k_τ depends on the the model and on τ). The model consists of equations (9), (10), (18) and (19) with $i_t = PLB$ (the lower bound still binding). It can be cast in matrix form consistent with Eggertsson and Woodford (2003):

$$\begin{bmatrix} \boldsymbol{P}_t \\ \boldsymbol{Z}_t \end{bmatrix} = \begin{bmatrix} \boldsymbol{A} & \boldsymbol{B} \\ \boldsymbol{C} & \boldsymbol{D} \end{bmatrix} \begin{bmatrix} \boldsymbol{P}_{t-1} \\ \boldsymbol{Z}_{t+!} \end{bmatrix} + \begin{bmatrix} \boldsymbol{M} \\ \boldsymbol{V} \end{bmatrix} \tag{29}$$

with $\begin{bmatrix} \boldsymbol{A} & \boldsymbol{B} \\ \boldsymbol{C} & \boldsymbol{D} \end{bmatrix} = \begin{bmatrix} 1 & -\kappa_1 & 0 & \lambda & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ & & & -\kappa_1 & 1 & 0 \\ & \mathbf{0}_{3\times3} & & 1 & 0 & 0 \\ & & & 0 & 0 & 1 \end{bmatrix}^{-1} \begin{bmatrix} \beta^{-1} & \beta^{-1}\kappa_2 & 0 & & & \\ (\beta\sigma)^{-1} & \beta^{-1}\beta_1 & \beta^{-2}\beta_2 & & \mathbf{0}_{3\times3} & \\ 0 & 1 & 0 & & & \\ & & & \kappa_2 & \beta_1 & \beta_2 \\ & \mathbf{0}_{3\times3} & & 1 & \sigma^{-1} & 0 \\ & & & 0 & 1 & 0 \end{bmatrix}$

and $\begin{bmatrix} \boldsymbol{M} \\ \boldsymbol{V} \end{bmatrix} = \begin{bmatrix} 1 & -\kappa_1 & 0 & \lambda & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ & & & -\kappa_1 & 1 & 0 \\ & \mathbf{0}_{3\times3} & & 1 & 0 & 0 \\ & & & 0 & 0 & 1 \end{bmatrix}^{-1} \begin{bmatrix} \mathbf{0}_{3\times1} \\ 0 \\ \sigma^{-1}(\bar{\pi} + r_t - PLB) \\ 0 \end{bmatrix}$. The recursive formulae derived by Eggertsson and Woodford (2003)[16] apply in a straightforward way to a solution that can be expressed for $t = \tau, \dots, \tau + k_\tau$ as:

$$\boldsymbol{P}_t = \boldsymbol{\Omega}^{t-\tau-k_\tau}\boldsymbol{P}_{t-1} + \boldsymbol{\Phi}^{t-\tau-k_\tau} \tag{30}$$

$$\boldsymbol{Z}_t = \boldsymbol{\Lambda}^{t-\tau-k_\tau}\boldsymbol{P}_{t-1} + \boldsymbol{\theta}^{t-\tau-k_\tau} \tag{31}$$

Phase 1 ranges from $t = 1$ to $t = \tau - 1$ and is characterized by the persisting shock, the binding lower bound on interest rate along with $\phi_{1,t} > 0$, and an uncertain date of future shock reversal that affects the expectations of economic agents regarding future economic developments. Let δ_t denote the probability that the shock will die out at t at the latest. This value shall be consistent with δ. These probabilities serve the purpose of computing expected future values of inflation and the output gap, taking into account that – over the next two periods – the shock may be reverted. This yields the model of the following form (note that future values of variables are understood as contingent upon the continuation of the shock):

$$\begin{bmatrix} \boldsymbol{P}_t \\ \boldsymbol{Z}_t \end{bmatrix} = \begin{bmatrix} \boldsymbol{A}_t & \boldsymbol{B}_t \\ \boldsymbol{C}_t & \boldsymbol{D}_t \end{bmatrix} \begin{bmatrix} \boldsymbol{P}_{t-1} \\ \boldsymbol{Z}_{t+1} \end{bmatrix} + \begin{bmatrix} \boldsymbol{M}_t \\ \boldsymbol{V}_t \end{bmatrix} \tag{32}$$

with $\begin{bmatrix} \boldsymbol{A}_t & \boldsymbol{B}_t \\ \boldsymbol{C}_t & \boldsymbol{D}_t \end{bmatrix} =$

$$\begin{bmatrix} 1 & -\kappa_1 & 0 & \lambda & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ E_t & F_t & 0 & -\kappa_1 & 1 & 0 \\ G_t & H_t & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}^{-1} \begin{bmatrix} \beta^{-1} & \beta^{-1}\kappa_2 & 0 & & & \\ (\beta\sigma)^{-1} & \beta^{-1}\beta_1 & \beta^{-2}\beta_2 & & \mathbf{0}_{3\times3} & \\ 0 & 1 & 0 & & & \\ 0 & I_t & 0 & \kappa_2(1-\delta_{t+1}) & \beta_1(1-\delta_{t+1}) & N_t \\ 0 & J_t & 0 & 1-\delta_{t+1} & \sigma^{-1}(1-\delta_{t+1}) & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

and $\begin{bmatrix} \boldsymbol{M}_t \\ \boldsymbol{V}_t \end{bmatrix} = \begin{bmatrix} 1 & -\kappa_1 & 0 & \lambda & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ E_t & F_t & 0 & -\kappa_1 & 1 & 0 \\ G_t & H_t & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}^{-1} \begin{bmatrix} \mathbf{0}_{3\times1} \\ K_t \\ L_t \\ 0 \end{bmatrix}$, whereby:

$E_t = -\beta_1\delta_{t+1}\Lambda_{21}^{t+1} - \beta_2\delta_{t+2}(\Lambda_{21}^{t+2}\Omega_{11}^{t+1} + \Lambda_{22}^{t+2}\Omega_{21}^{t+1}) - \kappa_2\delta_{t+1}\Lambda_{11}^{t+1}$
$F_t = -\beta_1\delta_{t+1}\Lambda_{22}^{t+1} - \beta_2\delta_{t+2}(\Lambda_{21}^{t+2}\Omega_{12}^{t+1} + \Lambda_{22}^{t+2}\Omega_{22}^{t+1} + \Lambda_{23}^{t+2}) - \kappa_2\delta_{t+1}\Lambda_{12}^{t+1}$
$G_t = -\delta_{t+1}(\Lambda_{11}^{t+1} + \sigma^{-1}\Lambda_{21}^{t+1})$
$H_t = -\delta_{t+1}(\Lambda_{12}^{t+1} + \sigma^{-1}\Lambda_{22}^{t+1})$
$I_t = \beta_1\delta_{t+1}\Lambda_{23}^{t+1} + \beta_2\delta_{t+2}(\Lambda_{21}^{t+2}\Omega_{13}^{t+1} + \Lambda_{22}^{t+2}\Omega_{23}^{t+1}) + \kappa_2\delta_{t+1}\Lambda_{13}^{t+1}$
$J_t = \delta_{t+1}(\Lambda_{13}^{t+1} + \sigma^{-1}\Lambda_{23}^{t+1})$
$K_t = \beta_2\delta_{t+2}\Lambda_{21}^{t+2}(\Phi_1^{t+1} + \Phi_2^{t+1}) + \beta_1\delta_{t+1}\theta_2^{t+1} + \beta_1\delta_{t+2}\theta_2^{t+2} + \kappa_2\delta_{t+1}\theta_1^{t+1}$

[16] $\boldsymbol{\Omega}^{t-\tau-k_\tau} = (\boldsymbol{I} - \boldsymbol{B}\boldsymbol{\Lambda}^{t-\tau-k_\tau-1})^{-1}\boldsymbol{A}$, $\boldsymbol{\Lambda}^{t-\tau-k_\tau} = \boldsymbol{C} + \boldsymbol{D}\boldsymbol{\Lambda}^{t-\tau-k_\tau-1}\boldsymbol{\Omega}^{t-\tau-k_\tau}$, $\boldsymbol{\Phi}^{t-\tau-k_\tau} = (\boldsymbol{I} - \boldsymbol{B}\boldsymbol{\Lambda}^{t-\tau-k_\tau-1})^{-1}(\boldsymbol{B}\boldsymbol{\theta}^{t-\tau-k_\tau-1} + \boldsymbol{M})$ and $\boldsymbol{\theta}^{t-\tau-k_\tau} = \boldsymbol{D}\boldsymbol{\Lambda}^{t-\tau-k_\tau-1}\boldsymbol{\Phi}^{t-\tau-k_\tau} + \boldsymbol{D}\boldsymbol{\theta}^{t-\tau-k_\tau-1} + \boldsymbol{V}$, with terminal conditions $\boldsymbol{\Omega}^0, \boldsymbol{\Lambda}^0$ (from Phase 3) and $\boldsymbol{\Phi}^0 = \boldsymbol{\theta}^0 = \mathbf{0}_{3\times1}$.

$L_t = \sigma^{-1}(\bar{\pi} + r_t - PLB) + \delta_{t+1}(\theta_1^{t+1} + \sigma^{-1}\theta_2^{t+1})$
$N_t = \beta_2(1 - \delta_{t+2})$
Using the above formulation with time-varying parameters as well as terminal conditions $\boldsymbol{B}_{S-2} = \boldsymbol{D}_{S-2} = \boldsymbol{0}$, $\boldsymbol{\Omega}^{\boldsymbol{S-2}} = \boldsymbol{A}_{S-2}$, $\boldsymbol{\Phi}^{\boldsymbol{S-2}} = \boldsymbol{M}_{S-2}$, $\boldsymbol{\Lambda}^{\boldsymbol{S-2}} = \boldsymbol{C}_{S-2}$, $\boldsymbol{\theta}^{\boldsymbol{S-2}} = \boldsymbol{V}_{S-2}$ (S is some arbitrarily remote date – until that date, the probability of shock reversal is assumed to be 1), we can apply the formulae from Eggertsson and Woodford (2003) in a straightforward way.[17]

Finally, we look for k_τ using the algorithm described by Eggertsson and Woodford (2003).

In the case of discretion, the solution – as in Subsection 3.4 – simplifies to 2 phases.

In phase 2 ($t = \tau$ and later), $y_t = \pi_t = 0$ as the central bank sets the nominal interest rate to bring the output gap to zero.

Phase 1 is characterized by an analogous setup to the case of commitment, i.e., agents' expectations are weighted averages of future developments under the binding or non-binding lower bound, in line with the respective probabilities. As under the non-binding lower bound $y_t = \pi_t = 0$ and the Lagrange multipliers are irrelevant, the lower block of equation (32) simplifies to:

$$\begin{bmatrix} -\kappa_1 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} y_t \\ \pi_t \\ \pi_{t+1} \end{bmatrix} =$$
$$\begin{bmatrix} \kappa_2(1-\delta_{t+1}) & \beta_1(1-\delta_{t+1}) & \beta_2(1-\delta_{t+2}) \\ 1-\delta_{t+1} & \sigma^{-1}(1-\delta_{t+1}) & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} y_{t+1} \\ \pi_{t+1} \\ \pi_{t+2} \end{bmatrix} + \begin{bmatrix} 0 \\ -\sigma^{-1}(PLB - \bar{\pi} - r_t) \\ 0 \end{bmatrix} \tag{33}$$

The solution for phase 1 is found on the basis of equation (33) and terminal conditions $\begin{bmatrix} y_{S-1} \\ \pi_{S-1} \\ \pi_S \end{bmatrix} = \boldsymbol{0}_{\boldsymbol{3\times3}}$.

3.6. Calibration

Our calibration strategy is to ensure that our model (and results) is comparable to Jung et al. (2005) based on the parameter set from Woodford (1999), similar to the calibration made by Eggertson and Woodford (2003). However, due to the changes in the structure of the model, this can be accomplished in a straightforward way only for a subset of parameters. Following Woodford (1999) and Jung et al. (2005), we set $\beta = 0.99$ and $\sigma = 0.157$.

Following Adam and Billi (2006), we set λ according to a micro-founded loss criterion. Note, however, that $\lambda = \frac{\kappa}{\varepsilon}$ does not hold any more under trend inflation.[18] To see this, consider the standard definition of the price level at *t* in the price-setting model *à la* Calvo:

$$P_t = \left[(1-\theta)\widetilde{P_t}^{1-\varepsilon} + \theta P_{t-1}^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} \tag{34}$$

This can be transformed into:

$$\Pi_t^{1-\varepsilon} = (1-\theta)X_t^{1-\varepsilon} + \theta \tag{35}$$

with Π_t denoting the gross inflation rate at *t*, while $X_t \stackrel{\text{def}}{=} \widetilde{P_t}/P_{t-1}$. This implies the steady-state value $\bar{X} = \left(\frac{\Pi^{1-\varepsilon}-\theta}{1-\theta}\right)^{\frac{1}{1-\varepsilon}}$. Log-linearizing around this steady state yields

$$\pi_t = \bar{\Pi}^{\varepsilon-1}(\bar{\Pi}^{1-\varepsilon} - \theta)^{\frac{-\varepsilon}{1-\varepsilon}}(1-\theta)^{\frac{1}{1-\varepsilon}}x_t \tag{36}$$

Note that under $\bar{\Pi} = 1$, expression (36) collapses to the standard formula $\pi_t = (1-\theta)x_t$. Now denote the parameter accompanying x_t in (36) as *c* for convenience of exposition. Expression

[17] $\boldsymbol{\Omega^t} = (\boldsymbol{I} - \boldsymbol{B}_t\boldsymbol{\Lambda}^{t+1})^{-1}\boldsymbol{A}_t$, $\boldsymbol{\Lambda^t} = \boldsymbol{C}_t + \boldsymbol{D}_t\boldsymbol{\Lambda}^{t+1}\boldsymbol{\Omega}^t$, $\boldsymbol{\Phi^t} = (\boldsymbol{I} - \boldsymbol{B}_t\boldsymbol{\Lambda}^{t+1})^{-1}(\boldsymbol{B}_t\boldsymbol{\theta}^{t+1} + \boldsymbol{M}_t)$ and $\boldsymbol{\theta^t} = \boldsymbol{D}_t\boldsymbol{\Lambda}^{t+1}\boldsymbol{\Phi}^t + \boldsymbol{D}_t\boldsymbol{\theta}^{t+1} + \boldsymbol{V}_t$.
[18] κ is the slope of the New Keynesian Phillips curve for $\bar{\pi} = 0$.

(36) shall be used in the derivation of the recursive definition of the intratemporal, cross-section variance of prices between producers. Woodford (2003, p. 695, formula E.8) substitutes $(1-\theta)^{-1}\pi_t$, which shall now be replaced by $c^{-1}\pi_t$. This leads to replacing equation (2.20) in Woodford (2003, p. 399) with the following (up to terms of order higher than 2 and terms independent of policy):

$$\Delta_t = \theta\Delta_{t-1} + \frac{1-\theta-c^2}{c^2}\pi_t^2 \tag{37}$$

Following Woodford (2003, p. 400), as a result of the forward iterative solution, we obtain:

$$\sum_{t=0}^{\infty}\beta^t\, var_n p_{n,t} = \frac{1}{1-\theta\beta}\frac{1-\theta-c^2}{c}\sum_{t=0}^{\infty}\beta^t\,\pi_t^2 \tag{38}$$

This leads to the following welfare criterion (cf. Eq. (2.22) in Woodford (2003, p. 400), up to a scaling constant, terms of higher order and terms independent of policy):

$$\mathcal{L}_t = \sum_{i=0}^{\infty}\beta^i\left[\pi_t^2 + \varepsilon^{-1}\frac{(1-\beta\theta)c^2}{1-\theta-c^2}(\sigma+\phi)y_t^2\right] \tag{39}$$

Equation (39) allows calibrating λ on the basis of β, ε, θ, σ, ϕ and $\overline{\Pi}$.

As regards the parameters of the Phillips curve, it is sufficient for the abovementioned authors to calibrate only $\beta = 0.99$ (i.e., the parameter on the one-period-ahead expected inflation rate) and $\kappa = 0.024$ (i.e., the parameter for the current output gap) under the assumption of zero steady-state inflation. This is not a feasible solution with our altered structure of the model and four reduced-form parameters in equation (10). Note that these parameters are interdependent and cannot vary freely, being based on the same subset of structural parameters.

All 4 parameters are based on β and σ but also on (i) Calvo probability θ, (ii) the Cobb-Douglas exponent on labour in the production function $1-\alpha$, (iii) Frisch elasticity of labour supply φ and (iv) elasticity of substitution between goods varieties ε. We calibrate α, φ and ε in line with the literature standards and, conditionally upon this, then set θ to match Woodford's (1999) $\kappa = 0.024$ in the standard Phillips curve.

In particular, we calibrate $1-\alpha$, φ and ε based on the works of Smets and Wouters (2002, 2003). The value of $1-\alpha = 0.7$ taken by the exponent on labour in the production function is widespread in the literature, resulting both from direct estimation attempts of the production function and from a direct calibration based on the labour share in national income. The value of Frisch elasticity of labour supply at $\varphi = 0.25$ seems to be relatively low, but the calibrations in the literature are quite scattered. For example, Christiano et al. (2005) assume a value of unity. However, in our case, such a change has only a marginal effect on the reduced form parameters in (10) and hence on our results. The calibration of $\varepsilon = 3$ in the New Keynesian monopolistic competition model is typically set to imply a mark-up of 50%. Additionally, even large changes in ε (that we consider conducting the robustness check) have no significant effect on our results. Ultimately, the set of 3 structural parameters based on Smets and Wouters (2002, 2003) and Woodford's (1999) calibration of $\kappa = 0.024$ together imply the calibration of the Calvo parameter at $\theta = 0.7505$.

The calibration of the shock size and persistence follows the previous literature on the ZLB with serially correlated disturbance of the natural interest rate. We set $\rho = 0.8$ as in Adam and Billi (2006, 2007). This value is also the central point of the interval from 0.75 to 0.85 considered by Levin et al. (2010). In our sensitivity analysis, we consider a wider range from 0.5 (the baseline value of Jung et al., 2005) to 0.9 (the maximum value considered by Adam and Billi, 2006, 2007). The initial shock size, ϵ_1, is calibrated to 0.05 as in the case of Levin et al. (2010). Note that this is 3.3 of (quarterly) standard deviations of this type of shock, as identified by Adam and Billi (2006, 2007). With respect to the alternative shock definition from Subsection 3.5, we set $\delta = 0.1$ like Eggertsson and Woodford (2003).

We calibrate the steady-state natural interest rate in line with Eq. 2 at the level consistent with β, σ and the growth rate of potential output equal to 0.02/4. The latter figure corresponds to the average growth rate of real GDP in the US economy according to Penn's World Tables 8.0 (since 1950). As a result, $\bar{r} = 0.0107$. Steady-state inflation is set at $\bar{\pi} = 0.02/4$. The same value is proposed as the PLB. Note that these calibrations, as well as the previous ones, are expressed in quarterly terms. This corresponds to annual values of $\bar{r}$ at 4.28% and $\bar{\pi}$ and PLB at 2%. As mentioned in the introduction, 2% matches the inflation target most frequently seen in advanced economies, as well as the floor for the policy rate of the Bank of England since its foundation in 1694 until 2009 (and of most other central banks too). Note that such a floor usually implied clearly positive real interest rates. When it was binding, it was often accompanied by deflation.[19] In our setting, the real interest rate at the PLB is lower. This is similar to most other studies on the ZLB (where both steady-state inflation and the floor for interest rates are nil).

(Table 1)

4. Results

As indicated in the introduction, four combinations of ZLB and PLB policy varying in terms of their credibility are considered:

(a) both policies are discretionary,
(b) both policies are pursued under commitment,
(c) PLB policy is pursued under commitment, while ZLB is discretionary,
(d) PLB policy is discretionary, whereas ZLB is pursued under commitment.

Of the first two combinations, case (a) seems to be of much more practical meaning than case (b). This stems not only from the observed reluctance of central banks to commit (recall the discussion from the introduction on the poor performance of major economies when the ZLB became binding) but also from the adverse effect of a severe negative shock on economic agents' trust in central banks that conditions their credibility (see, e.g., Wälti, 2012). Credibility is crucially important to overcome the problem of the time inconsistency of such a commitment (see, e.g., Levine et al., 2008 or Woodford, 2012). Besides, the commitment entails serious practical problems. For example, Eggertsson and Proulx (2015) prove that it would require from the central bank asset purchases of completely infeasible scale. In turn, Swanson (2015) finds that any effects of forward guidance have been thus far surprisingly short-lived.

We scrutinize the remaining two combinations because one cannot prejudge which type of policy, ZLB or PLB, is more likely to be credible. On the one hand, the ZLB policy signals a dovish bias. By contrast, PLB can be considered a sign of hawkish bias, limiting the actual probability of the central bank allowing inflation to exceed the target. On the other hand, the empirical evidence, albeit very scarce, suggests that the ZLB policy can undermine trust in the central bank (Albinowski at al., 2014). Note that if discretionary policy is more likely in practice than policy under commitment, when the lower bound binds, both the cases (c) and (d) are more likely than case (b) but less likely than case (a).

We start the comparison of the ZLB and PLB policies as if the ZLB policy had no side (adverse) effects such as strengthened post-crisis financial frictions, delayed restructuring or heightened uncertainty. It is not a surprise that under this assumption, the ZLB policy is, in general, welfare enhancing relative to the PLB policy. That being said, the central bank's credibility is of crucial importance (see below).[20]

In case (a), when both policies fail to prevent severe and long recession, the difference in the depth of negative output gap and resulting deflation is large. In case (b), the difference is

[19] At the end of the 19th century, the price level in the UK was about a third of the level from the beginning of the century

[20] When the baseline model's calibration is applied, the micro funded loss function amounts to 0.0096519 under the ZLB and to 0.027677 under the PLB if both policies are discretionary, as compared to 0.0012064 under the ZLB and 0.0019718 under the PLB if they are pursued under commitment.

less profound. Still, the ZLB policy makes it possible to clearly reduce the output gap in comparison with the PLB policy. Moreover, the subsequent overshooting and accompanying inflation needed to alleviate the recession are weaker and more short lived than under the PLB policy. By contrast, in case (c), the ZLB policy underperforms the PLB policy in terms of welfare. Although the former implies lower average nominal interest rates, it is the latter that results in a milder and shorter recession. This result suggests that when the economy is hit by a severe shock, the commitment, if credible, counts more for the welfare performance than the exact value of the effective lower bound does (as long as this value is reasonably low). It is true that the weight of the central bank's credibility is already highlighted in many other studies on the ZLB (see, e.g., Adam and Billi, 2006 or Eggertsson and Woodford, 2003). However, while they prove that it provides central banks with the ability to stabilize the economy when the ZLB binds, we go a step further and argue that the credibility can deprive central banks of strong justification for aggressive interest rate cuts all the way to zero. Finally, in case (d), both the lower bound value and an inability to commit work to the detriment of the PLB policy. Thus, it generates much larger welfare losses than the ZLB policy does (see Figure 5).

(Figure 5)

Interestingly, the value of the lower bound (under the calibration considered) has no strong effect on the length of period over which the interest rate is held at the lower bound. In the case of ZLB policy, the period lasts 7 quarters under discretion and 8 quarters under commitment. In the case of PLB policy, it is longer by 1 quarter only.

Next, we relax the assumption of no side effects from the ZLB policy. We approximate them instead as the larger inertia of shock to r_t under the ZLB policy for reasons explained in section 2. We check how much less persistent a shock under the PLB policy would have to be compared to one dealt under the ZLB policy so that the welfare losses of the PLB did not exceed those incurred under the ZLB.

It turns out that as long as both policies are of similar credibility, i.e., in case (a) and (b), the difference in ρ required for the PLB policy to pay off is quite moderate. Under the baseline calibration, it amounts to 0.063 in case (a) and 0.092 in case (b). Thus, it is lower when the central bank fails to commit (and welfare losses are large) than otherwise. Recall that case (a) is the most likely combination of the ZLB and PLB policies. Note that the dispersion in the baseline value of ρ considered in various papers on the topic (cf. Adam and Billi, 2006, 2007 and Jung et al., 2005) is three to five times as large as required in case (b) and (a), respectively.[21]

The required difference in ρ also seems quite moderate if compared to some empirics. It implies a ratio of shock half-lives under the ZLB and PLB policy of 1.368 in case (a) and 1.548 in case (b), respectively. By comparison, the period since the end of the Great Recession is already 1.750 times longer than the average time needed to close the output gap after previous recessions in the United States[22], and 35.4% of the initial gap still needs to be closed[23] (cf. Figure 6).

(Figure 6)

[21] We do not describe case (c) here because in this case, PLB policy dominates the ZLB policy in terms of welfare, even if the ZLB policy has no side effects.

[22] In the calculation, the recession of q1 1980:q3 1980 is combined with the recession of q3 1981:q4 1982 because the output gap after the former was not closed until the beginning of the latter. The end of the former is taken as the starting point of the closing of the output gap. The period since the end of the Great Recession would be 2.161 times longer than the average time of the closing of the output gap after previous recessions if the average time was measured from the bottom of the output gap and not the end of the recession as announced by the NBER.

[23] Please note that this comparison does not by any standard prejudge to what extent, if any, interest rates close to zero have been responsible for the deceleration of the output gap closing after the Great Recession as compared to previous recoveries. A similar caveat applies to the comparisons in the next two paragraphs.

In turn, updated estimates of r_t from Laubach and Williams (2003) point to a downward shift in the trend in r_t after q4 2008 when the Fed funds rate was cut to near zero. The shift implies that r_t was then hit by a shock, which if not permanent, has been of such high persistency that the process of its dying out could hardly be identified thus far.[24] This interpretation seems to be shared by the Fed. Seven years after the outburst of the global financial crisis Yellen (2015, p. 12-13) acknowledges that r_t "is at present well below its historical average", "is anticipated to rise only gradually over time" and "may not, in fact, recover as much or as quickly as [she] anticipate[s]." Indeed, even the highest estimates of r_t projected by Pescatori and Turunen (2015) at the end of a 5-year projection horizon stay below the FOMC members' median evaluation of $\bar{r}$, not to mention the historical average of r_t.

(Figure 7)

Finally, in correspondence with a very gradual closing of the output gap and persistently low r_t, there has been the longest period ever with no lift-off of the Fed funds rate as well as the longest period since at least 1950 that the Fed has been on hold during recovery. The longest period from the interest rate cut to the first hike was previously 63 months compared to 83 months as expected now (BofA Merrill Lynch, 2015). That period began in August 1937 and ended in September 1942 and was the period of ZLB policy, like the current one. In turn, the previous longest timespan from the end of a recession until the first hike lasted 35 months; the current expectation is 77 months (Deutsche Bank, 2015).[25]

Only in case (d) would the required difference in ρ have to be large for the PLB policy to outperform the ZLB policy in terms of welfare. This is the only case where the break-even ρ under the PLB policy (0.425) is out of the range considered in the literature on the ZLB (see Figure 8). This is so because PLB policy implies higher interest rates compared to the ZLB policy, not only until the lower bound binds but for some time later as well. This case highlights again the significance of a central bank's credibility. Should interest rate cuts to zero condition it, the central bank would not have to attach much weight to the possible side effects of the ZLB policy.

(Figure 8)

Interestingly, the more persistent or the larger the shock, the lower the required difference in ρ and thereby the more limited, in relative terms, the implied difference in the half-life of ϵ_1 (see table 2). This relationship casts doubt on aggressive interest rate cuts to zero in response to a severe negative shock, which since Eggertsson and Woodford (2003) have been unanimously advocated by the whole body of literature on the ZLB that envisages a 'fundamental' shock. The results suggest, instead, that the more severe the shock, the more cautious the central bank's response should be, and this is especially so when it is reluctant to commit or its credibility is dubious (which is – let us reiterate – quite likely given the adverse effect of a severe shock on economic agents' trust in the central bank). Note that the reason for the suggested caution is not the need to preserve dry powder for future emergencies, as older papers have argued. It is the risk of the side effects of ZLB policy.

[24] There is no trend and hence no shift in trend in the estimates of r_t derived by Barsky et al. (2014) from a DSGE model. However, those estimates confirm that r_t was hit by a large negative shock of a very persistent nature around q4 2008. Since then, the estimates from Barsky et al. (2014) and the updated estimates from Laubach and Williams (2003) stay stubbornly near zero and are quite close to each other, which was rarely the case previously.

[25] Even if one considers the shadow rate estimated for the United States by Krippner (2014), to take unconventional monetary policy measures undertaken by the Fed into full account, the last period of recovery with no tightening of monetary policy was still the longest by far. It lasted 46 months.

(Table 2)

We check for the sensitivity of our results to the assertion that certain costs related to rapid restructuring can be avoided or reduced if restructuring is slow. We approximate these costs by an increase in ϵ_1 under the PLB policy. We verify how large the implied ϵ_1 would have to be under this policy to push the break-even ρ out of the range considered in the literature on the ZLB. It follows from the baseline calibration that the implied ϵ_1 would have to exceed several times (quarterly) the standard deviations of the shock under consideration, as identified by Adam and Billi (2006, 2007). The respective ratio amounts to 6.0 in case (a), 4.3 in case (b), and 9.4 in case (c) (see Figure 9).[26]

(Figure 9)

We check the robustness of our findings to changes in the model's calibration (see table 3). It follows that potential output growth has almost no impact on the required difference in ρ. In the range considered for potential output growth, this difference increases (to a very limited extent) mainly when potential output growth is high (3% or above). Thus, if the ZLB policy entails side effects, it should be avoided by countries with both fast and slow economic growth.

The value of $\bar{\pi}$ has a more significant but still limited impact on the required difference in ρ. The difference increases when the inflation target is set higher, but the increase is very weak. This weakness should be expected given the findings on PLB, as setting a PLB is functionally quite close in the NK model to downward revision of $\bar{\pi}$. The result implies that countries with both high and low inflation targets should be discouraged from the use of ZLB policy by its possible side effects.

As far as parameters related to the elasticity of economy are concerned, φ has almost no influence on the required difference in ρ. Even a significant increase in φ leads to a limited rise in the required difference in ρ, with the exception of case (c), where the relationship is opposite albeit still very weak. Recall that in this case, PLB policy dominates ZLB policy in terms of welfare, irrespective of any side effects of the latter. True, this dominance is a bit weaker when φ is lower than in the baseline calibration, but it still holds comfortably. The case of ε is not significantly different. Its impact on the required difference in ρ is primarily related to changes in λ and floppy (at least as long as it does not fall below 1, i.e., remains consistent with empirical studies on mark-ups).[27] The required difference in ρ very feebly increases with a rising ε (except for a very high value of ε when it decreases) if the ZLB policy is discretionary. Otherwise, the relationship is opposite and stronger, albeit still very weak. First and foremost, however, if anything it strengthens the conclusions drawn under the baseline calibration. Namely, in case (b), the break-even ρ remains within the range considered in the literature on the ZLB even for extremely low ε (and as a result very high λ), while in case (d) a moderately high ε raises its value to the level from that range. Put differently, even if the ZLB policy is pursued under commitment, fairly limited side effects of the ZLB policy should be enough for PLB policy to pay off in terms of welfare. This holds for any ε if the PLB policy is under commitment too and for a moderately high ε if central banks fail to commit under PLB. Similarly with regard to θ, it has almost no impact on the required difference in ρ if the ZLB policy is discretionary. A certain effect, however weak, appears when the ZLB policy is pursued under commitment. In such a case, the required difference in ρ decreases somewhat with a rising θ. This is irrelevant in case (b), where the break-even ρ remains within the range

[26] We do not describe case (d) here because in this case, the break-even ρ under the PLB policy is out of the range of ρ considered in the literature irrespective of whether fast restructuring entails extra costs.

[27] Recall that λ depends on ε. We consider a wider range of ε than justified by the results of empirical studies on mark-ups to cover values of λ that appear in the literature on the ZLB.

considered in the literature on the topic for any value of θ. Nevertheless, in case (d), a bit larger θ than in the baseline calibration suffices to increase the break-even ρ to the level from that range. Overall, countries with both flexible and rigid economies should be discouraged from using the ZLB policy by its possible side effects. Any differences in results for these economies are small. However, if one wants to be more specific, more valid reasons for avoiding the ZLB policy are displayed by countries with a more rigid labour supply and a higher degree of nominal rigidities, although more fierce competition (manifested in lower mark-ups).

(Table 3)

We also check how a simultaneous change of all parameters to the level implying the largest required difference in ρ, as indicated in table 3, would affect our findings. It follows that if the central bank fails to commit under the ZLB policy, then irrespective of its credibility under the PLB policy, the break-even ρ remains within the range considered in the literature on the ZLB (see Figure 10).

(Figure 10)

Case (b) requires some discussion. In this case, there is no break-even ρ under the assumed calibration because the fast $y_{t+1}^P - y_t^P$ and high $\bar{\pi}$ raise the nominal interest rate in the steady state high above the established lower bound. As a result, below a certain value of ρ (0.69 in the calibration considered), the loss function under PLB assumes a constant value regardless of ρ (while remaining larger than under the ZLB) because at such a value of ρ, the lower bound binds for only one period (two periods for a value of 0.70). For all ρ, at which the lower bound binds for only one period, the output gap and inflation follow the same path, which results in the same loss function values. The construction of the model requires at least two periods of lower bound binding for the relevance of ρ for welfare losses under the lower bound.

Ultimately, we apply the approach proposed by Eggertsson and Woodford (2003) instead of following Jung et al. (2005). It follows that our main findings are fairly robust to such a change in the definition of a shock that makes the ZLB bind. Specifically, in case (a) (which, to reiterate, is the most likely combination of ZLB and PLB policies), the difference in δ required for the PLB policy to pay off is rather moderate. Under the baseline calibration, its absolute value amounts to 0.02 and implies a lengthening of the expected period of reversion of r_t to its steady-state value by 1.6(6) quarters under ZLB policy compared to PLB policy. In case (b), the required difference in δ is clearly larger (see Figure 11). Its absolute value increases to 0.11. As a result, the implied lengthening of the expected period of reversion of r_t rises to more than 5 quarters.

(Figure 11)

The two remaining cases, (c) and (d), confirm the crucial importance of the central bank's commitment for welfare when the lower bound binds. In case (c), PLB policy would strongly outperform ZLB policy in terms of welfare even if ZLB policy had no adverse side effects (and had positive side effects). In both cases, the welfare equivalence between ZLB and PLB policies cannot be achieved for any sensible combination of δ. Hence, as in the approach following Jung et al. (2005), the central bank's commitment (if credible) matters more for welfare than, on the one hand, the exact value of the effective lower bound (as long as this value is reasonably low) and, on the other hand, the possible side effects of interest rates being close to zero, provided that such a low level is necessary for the commitment to be credible.

In summary, the findings provide support for cautiousness with regard to cutting interest rates to zero. Note that PLB would by no means rule out quantitative easing in order to avoid possible panic in systemically important segments of the financial sector after the outburst of the financial crisis. Quantitative easing under PLB policy would be in line with Bagehot's (1892) prescription of lending freely to solvent banks against good collateral and at penalty rates. It would also contribute, in some sense, to central banks' return to their original task of interest rate stabilization (see, e.g., Goodhart, 1988; cf. figure 3). Interestingly, one may draw quite similar conclusion from Woodford (2015) (although it is based there on different premises). He proves that quantitative easing can be as effective as interest rates cuts in coping with severe negative shocks, but it creates lower risk for future financial stability.[28]

The question arises whether establishing a PLB suits situations such as the current one in the major economies, where interest rates have already been close to zero for many years. If the approach developed by Jung et al. (2005) correctly describes how the lower bound ceases to bind, the answer is: not necessarily, for four reasons. With that being said, reservations apply to the answer.

First, as periods go by since the ZLB has started to bind, a large part of initial shock ϵ_1 can expire. In other words, even if interest rates close to zero promoted forbearance lending, hindered post-crisis restructuring or contributed to heightened uncertainty, they would postpone the return of r_t to the steady state but would not rule such a return out. The state of a modelled economy in a given period $k>0$ can be fully described with the help of a shock ϵ_k, such as:

$$\epsilon_k = \epsilon_1 \tilde{\rho}^{\,k-1} < \epsilon_1 \tag{40}$$

Recall table 2, which reports that the milder the shock to r_t, the less likely the dominance of PLB over the ZLB in terms of welfare (the larger the side effects of ZLB required for such dominance). One obvious caveat applies here. It follows from Eq. 40 that ϵ_k/ϵ_1 depends not only on k but on $\tilde{\rho}$ as well. The larger the $\tilde{\rho}$, the less weighing with the passage of time on the chances of PLB dominating the ZLB. Put differently, raising interest rates from zero to the PLB value to curb forbearance lending or foster post-crisis restructuring is more likely to pay off in an economy in which forbearance lending has been massive and post-crisis restructuring slow and that is therefore far from being advanced in spite of the long time k having passed since the outburst of the crisis. These conditions are more likely to be met in an economy with a banking-based financial sector[29], loans of a recourse debt nature and high costs of dealing with insolvency.

Second, delays in restructuring are likely to increase costs of rapid restructuring, which are avoided or mitigated as long as restructuring is slow. The delays lengthen the period for which capital and labour are used in a given application. This lengthening gives at least some of the production factors a more specific nature. Moreover, a low entry rate reduces the share of firms fully adapted to the current economic conditions, while the struggles of many existing firms to maintain the status quo result in a lower and lower percentage of entities easily adapting to new conditions. Note, however, that such changes in production factors' specificity and firms' need and ability to adapt increase the sensitivity of the economy not only to the establishment of PLB but to any shock.

Third, raising interest rates from zero to the PLB value can trigger a fiscal crisis if government has been running a primary deficit d_p under ZLB policy. Provided that investors consider the probability of stabilizing the sovereign debt-to-GDP ratio b_t in any future period

[28] Nevertheless the finding has to be taken with caution because in Woodford's model financial fragility results exclusively from excessive reliance of banks on collateralized short term debt. It does not consider neither "reach for yield", nor rise in leverage in response to dampened volatility, i.e. two phenomena which quantitative easing is often blamed for (see, e.g. BIS, 2014).

[29] Simons (1936) was probably the first to claim that capital market funding promotes adjustment speed relative to bank funding. In turn, Allard and Blavy (2011) were among the first to verify this claim empirically. Notably, although they found some support in the data for that claim, their findings are not unequivocal given the differences in product and labour market flexibility across analysed countries.

as equal to $\tilde{\delta}$ and given that there is no change in d_p before stabilization, the value of sovereign debt b_{stab} that they expect at the moment of stabilization is given by Eq. 41 (cf. Blanchard, 1990):

$$E(b_{stab}) = \int_k^{\infty} \left(\left(b_k + \frac{d_p}{i - \pi - \Delta y^P} \right) e^{(i - \pi - \Delta y^P)(t-k)} - \frac{d_p}{i - \pi - \Delta y^P} \right) \tilde{\delta} e^{-\tilde{\delta}(t-k)} dt =$$

$$= \begin{cases} \infty, \; for \quad \tilde{\delta} + \pi + \Delta y^P \leq i \\ \dfrac{\tilde{\delta}\left(b_k + \dfrac{d_p}{i - \pi - \Delta y^P} \right)}{\tilde{\delta} + \pi + \Delta y^P - i} - \dfrac{d_p}{i - \pi - \Delta y^P}, \; for \quad \tilde{\delta} + \pi + \Delta y^P > i \end{cases} \tag{41}$$

It follows that in the case of the zero interest rate, even marginally positive $\tilde{\delta}$ is enough to reassure investors that sovereign debt is sustainable, unless they expect the economy to shrink in nominal terms. At the same time, with a very low value of $\tilde{\delta}$, there is a substantial risk that after any increase in the interest rate, investors will lose their faith in sustainability of sovereign debt. Note, however, that in the real world, ZLB policy may encourage government to increase d_p, $\tilde{\delta}$ may decline once b_t becomes large (cf. Conesa and Kehoe, 2014), and a large b_t may give rise to fears of the economy shrinking (cf. Reinhart et al., 2012). Thus, a fiscal crisis may also occur under ZLB policy. In such a case, b_t is likely to be larger. Taylor (2012) (among others) documents that the larger the sovereign debt, the more costly the crisis.

Fourth, a shift from the ZLB to PLB policy creates a risk that the public would blame the central bank for the whole negative output gap (and not only for the costs of fast restructuring). Taking into account the government willingness to keep soft budget constraints, a general perception that the central bank and not the crisis is responsible for the poor performance of the economy could put the central bank's independence at risk and result in policy reversal. Note that raising the interest rate from zero to the PLB value when inflation deviates from the target and the output gap is deeply negative could be viewed as inconsistent with the central bank's mandate. In addition, such a shift requires that the central bank admit that the previous monetary policy was wrong. The image of an erring institution would make it easier to attack the PLB policy as unsound by the beneficiaries of the ZLB policy. At the same time, the ZLB policy has provided them with funds for lobbying, which they would not have had had they been forced to restructure immediately after the crisis outburst. Overall, the late establishment of a PLB could be infeasible even if it was desirable from a social welfare perspective.

5. Conclusions

If the ZLB policy has no (adverse) side effects such as strengthened post-crisis financial frictions, delayed restructuring or heightened uncertainty, it is, in general, welfare-enhancing relative to the PLB policy. However, the credibility of the central bank is of crucial importance. If the central bank failed to commit under the ZLB policy, although its commitment under the PLB policy was perceived as credible, the latter policy would outperform the former in terms of welfare. In turn, given similar credibility for both policies, quite moderate side effects of the ZLB policy are enough for the PLB policy to pay off in terms of welfare. This held especially when central banks failed to commit, and even if restructuring, fostered by the PLB policy, entailed some costs that could be reduced or even avoided through slow restructuring. Moreover, the larger and the more persistent the shock, the more moderate the side effects required for PLB policy dominance over ZLB policy in terms of welfare. Only if the ZLB helped the central bank to credibly commit and the PLB policy undermined the central bank's credibility would the required side effects have to be large. A robustness check suggests that the findings hold for economies with both fast and slow potential output growth, with a low and higher inflation target, either flexible or more rigid. If anything, they are more robust for economies with slow potential output growth, a low inflation target, and strong rigidities – nominal and in the labour supply, although more fierce competition. The main findings are also fairly robust to changes in the definition of shock proposed by Eggertsson and Woodford (2003).

Our findings indicate that there are two directions of particular policy relevance for future research on ZLB. First, it should focus on what makes a central bank commitment credible and what harms its credibility. Second, quantitative evaluation of ZLB policy effects on post-crisis financial frictions, restructuring and uncertainty should be given high priority in the research agenda.

This paper is the first step to accommodate both the positive and side effects of the ZLB policy (or extremely accommodative policy in general). However, further steps should follow to establish the optimal central bank response to severe shock. The paper suggests that aggressive interest rate cuts to zero may not be the right response. Central banks should perhaps establish a PLB instead and use quantitative easing to avoid panic in systemically important segments of the financial sector. Bagehot (1892) could be right.

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References:

Adam K., Billi R. M. (2006) "Optimal Monetary Policy under Commitment with a Zero Bound on Nominal Interest Rates." *Journal of Money, Credit and Banking*. 38(7): 1877-1905

Adam K., Billi R. M. (2007) "Discretionary monetary policy and the zero lower bound on nominal interest rates", *Journal of Monetary Economics* 54(3): 728-752

Adrian T., Shin H. S. (2010) "Liquidity and leverage." *Journal of Financial Intermediation*. 19(3): 418-437

Adrian T., Shin H. S. (2014) "Procyclical Leverage and Value-at-Risk." *Review of Financial Studies*. 27 (2): 373-403

Ahearne A. G., Shinada N. (2005) "Zombie firms and economic stagnation in Japan." *International Economics and Economic Policy*. 2(4): 363-381

Albertazzi U., Marchetti D. J. (2010) "Credit supply, flight to quality and evergreening: an analysis of bank – firm relationships after Lehman." *Banca D'Italia Temi di Discussione (Working Paper.)* 756

Albinowski M., Ciżkowicz P., Rzońca A. (2014) "Links between the trust in the ECB and its interest rate policy." *Applied Economics*. 46(25): 3090-3106

Allard J., Blavy R. (2011) "Market Phoenixes and Banking Ducks. Are Recoveries Faster in Market-Based Financial Systems?" *IMF Working Paper*. 11/213

Altunbas Y., Gambacorta L., Marqués-Ibáñez D. (2014),"Does Monetary Policy Affect Bank Risk?" *International Journal of Central Banking*. 10(1): 95-136

Andrés J., Arce O. (2009) "Banking Competition, Housing Prices and Macroeconomic Stability". *Banco de España Working Paper*. 0830

Andrews D., Criscuolo Ch., Gal P. N. (2015), "Frontier Firms, Technology Diffusion and Public Policy: Micro Evidence from OECD Countries." *The Future of Productivity: Main Background Paper*. *OECD.* Paris

Angeloni I., Faia E. (2013) "Capital regulation and monetary policy with fragile banks." *Journal of Monetary Economics*. 60(3): 311-324

Arikawa Y., Miyajima H. (2007) "Relationship Banking in post Bubble Japan:Co-existence of soft-and hard budget constraint", in: *Corporate Governance in Japan: Institutional Change and Organizational Diversity*. Aoki M., Jackson G., Miyajima H. [eds.] Oxford, New York: Oxford University Press

Arrowsmith M., Griffiths M., Franklin J., Wohlmann E., Young G., Gregory D. (2014) "SME forbearance and its implications for monetary and financial stability." *Bank of England Quarterly Bulletin*. 2013 Q4: 296-303

Ascari, G. (2004), „Staggered price and trend inflation: some nuisances", *Review of Economic Dynamics* 7: 642–67

Bagehot W. (1892) *Lombard Street: A Description of the Money Market.* London: Kegan Paul, French, Trübner & Co Ltd

Bakhshi H., Khan H., Burriel-Llombart P., Rudolf B. (2007) „The New Keynesian Phillips curve under trend inflation and strategic complementarity", *Journal of Macroeconomics* 29: 37–59

BofA Merrill Lynch (2015) *The Thundering Word. The Policy Flip of 2016*. London: Bank of America Merrill Lynch Global Research. October 15

Barnett A., Batten S., Chiu A., Franklin J., Sebastiá-Barriel M. (2014a) "The UK productivity puzzle." Bank of England Quarterly Bulletin. 2014 Q2: 114-128

Barnett A., Broadbent B., Chiu A., Franklin J., Miller H. (2014b) "Impaired capital reallocation and productivity." National Institute Economic Review. 228: R35-R48

Barsky R., Justiniano A., Melosi L. (2014) "The Natural Rate of Interest and Its Usefulness for Monetary Policy." *American Economic Revie: Papers and Proceedings*. 104(5): 37-43

Basu S., Fernald J., Fisher J., Kimball M. (2013) “Sector-Specific Technical Change.” *mimeo*
Basu S., Fernald J., Kimball M. (2006) “Are Technology Improvements Contractionary?” *American Economic Review*. 96(5): 1418-1448
Bech M. L., Gambacorta L., Kharroubi E. (2014): “Monetary Policy in a Downturn: Are Financial Crises Special?”, *International Finance*, 17(1): 99-119
Benhabib J., Schmitt-Grohé S., Uribe M. (2001) “The Perils of Taylor Rules.” *Journal of Economic Theory*. 96(1): 40-69
Bernanke B. S. (2012) “Monetary Policy since the Onset of the Crisis.” *Speech delivered at the Federal Reserve Bank of Kansas City Economic Symposium, Jackson Hole, Wyoming.* August 31
BIS (2010) *BIS 80th Annual Report.* Basel: Bank For International Settlements
BIS (2012) *BIS 82nd Annual Report.* Basel: Bank For International Settlements
BIS (2013) *BIS 83rd Annual Report*. Basel: Bank for International Settlements
BIS (2014) *BIS 84th Annual Report*. Basel: Bank for International Settlements
Blanchard O. J. (1990) “Comment on Giavazzi and Pagano.” *NBER Macroeconomics Annual*. 1990
Blanchard O. J., Dell’Ariccia G., Mauro P. (2010) “Rethinking Macroeconomic Policy.” *Journal of Money, Credit and Banking*. 42(s1): 199-215
Bordo M. D., Landon-Lane J. (2013) “Does Expansionary Monetary Policy Cause Asset Price Booms? ; Some Historical and Empirical Evidence.” *NBER Working Paper*. 19585
Borio C. E. V. (2014) "The financial cycle and macroeconomics: What have we learnt?" *Journal of Banking & Finance*. 45(C): 182-198
Borio C. E. V., White W. R. (2003)"Whither monetary and financial stability: the implications of evolving policy regimes," *Federal Reserve Bank of Kansas City Proceedings - Economic Policy Symposium - Jackson Hole*. 2003:131-211.
Borio C. E. V., Zhu H. (2008) “Capital regulation, risk-taking and monetary policy: a missing link in the transmission mechanism?” *Journal of Financial Stability*. 8(4): 236-251
Caballero R. J. (2007) *Specificity and Macroeconomics of Restructuring*. Cambridge. London: MIT Press
Caballero R. J., Hoshi T., Kashyap A. K. (2008) “Zombie Lending and Depressed Restructuring in Japan” *American Economic Review.* 98(5): 1943-1977
Campbell J. R., Evans Ch., Fisher J. D. M., Justiniano A. (2012) “Macroeconomic Effects of Federal Reserve Forward Guidance.” Brookings Papers on Economic Activity. 1(2012): 1-80
Chen S., Kim M., Otte M., Wiseman K., Zdzienicka A. (2015) “Private Sector Deleveraging and Growth Following Busts.” *IMF Working Paper*. 15/35
Christiano L. J., Eichenbaum M., Evans C. L. (2005) „Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy”, *Journal of Political Economy,* 115(1): 1-45
Ciżkowicz P., Rzońca A. (2014) “Interest rates close to zero, post-crisis restructuring and natural interest rate.” *Prague Economic Papers*. 3(2014): 315-329.
Claessens S., Kose M. A., Laeven L., Valencia F. [eds.] (2013) *Financial Crises. Causes, Consequences, and Policy Responses*. Washington: International Monetary Fund
Cogley T., Sbordone A. M. (2008), „Trend Inflation, Indexation, and Inflation Persistence in the New Keynesian Phillips Curve”, *American Economic Review* 98(5): 2101–2126
Conesa J. C., Kehoe T. J. (2014) “Is It Too Late to Bail Out the Troubled Countries in the Eurozone?” *American Economic Review*. 104(5): 88-93
Davis S. J., Haltiwanger J. (2014) “Labor Market Fluidity and Economic Performance.” *NBER Working Paper*. 20479
Deutsche Bank (2013) *Default Study 2013. Analysing a Decade of Record Low HY Defaults*. London: Deutsche Bank Markets Research. Deutsche Bank AG

Deutsche Bank (2015) *Long-Term Asset Return Study. Scaling The Peaks*. London: Deutsche Bank Markets Research. Deutsche Bank AG

Diamond D. W., Rajan R. G. (2009) "The Credit Crisis: Conjectures about Causes and Remedies" *American Economic Review. Papers and Proceedings.* 99(2): 606-610

Dugger R. H., Ubide A. (2004) "Structural Traps. Politics and Monetary Policy." *International Finance.* 7(1): 85-116

Eggertsson G. B. (2003) "How to Fight Deflation in a Liquidity Trap: Committing to Being Irresponsible". *IMF Working Paper.* 03/64

Eggertsson G. B. (2006), "The Deflation Bias and Committing to Being Irresponsible", *Journal of Money, Credit and Banking,* Vol. 38, Issue 2, pp. 283-321

Eggertsson G. B. (2011) "What Fiscal Policy is Effective at Zero Interest Rates?" *2010 NBER Macroeconomic Annual* 25: 59-112

Eggertsson G. B., Krugman P. (2012) "Debt, Deleveraging, and the Liquidity Trap: A Fisher-Minsky-Koo Approach." *Quarterly Journal of Economics*, 127: 1469-1513

Eggertsson G. B., Proulx K. B. (2015) "The central Bank Sheet as a Commitment Device." *Paper presented at the 19th Annual Conference of Central Bank of Chile "Monetary Policy through Asset Markets: Lessons from Unconventional Measures and Implications for an Integrated World*. Santiago de Chile. November 19-20

Eggertsson G. B., Woodford M. (2003) "The Zero Bound in Interest Rates and Optimal Monetary Policy" *Brookings Papers on Economic Activity.* 34(1): 139-235

Farhi E., Tirole J. (2012) "Collective Moral Hazard, Maturity Mismatch, and Systemic Bailouts." *American Economic Review*. 102(1): 60-93

Fernald J. (2014) "A Quarterly, Utilization-Adjusted Series on Total Factor Productivity." *Federal Reserve Bank of San Francisco Working Paper*. 2012-19

Foster L., Grim Ch., Haltiwanger J. (2014)"Reallocation in the Great Recession: Cleansing or Not?." *NBER Working Paper*. 20427

Fukao K. (2013)"Explaining Japan's Unproductive Two Decades." Asian Economic Policy Review. 8(2): 193-213

Gali J. (2008), „Monetary policy, inflation, and the business cycle: an introduction to the New Keynesian framework", Princeton University Press, Princeton/Woodstock.

Gali J., Smets F., Wouters R. (2012) "Slow Recoveries: A Structural Interpretation." *Journal of Money, Credit and Banking*. 44(s2): 9-30.

Gesell S. (1958 [1916 – first edition]) *The Natural Economic Order*. London: Peter Owen Ltd

Goodhart Ch. A. G. (1988) The evolution of central banks, Cambridge, MA: MIT Press

Hamao Y., Mei J., Xu Y. (2007) "Unique Symptoms of Japanese Stagnation: An Equity Market Perspective". *Journal of Money, Credit and Banking. 39(4)*: 901-923

Hansen A. H. (1939) "Economic Progress and Declining Population Growth." *American Economic Review*. 29(1): 1-15

Homer S., Sylla R. E. (2005) *History of interest rates.* Hoboken: Wiley

Issing O.(2012)"The Mayekawa Lecture: Central Banks – Paradise Lost." *Monetary and Economic Studies*. 30(2012): 55-74

Jarocinski M., Smets F. R. (2008) "House prices and the stance of monetary policy." *Federal Reserve Bank of St. Louis Review,* July: 339-366

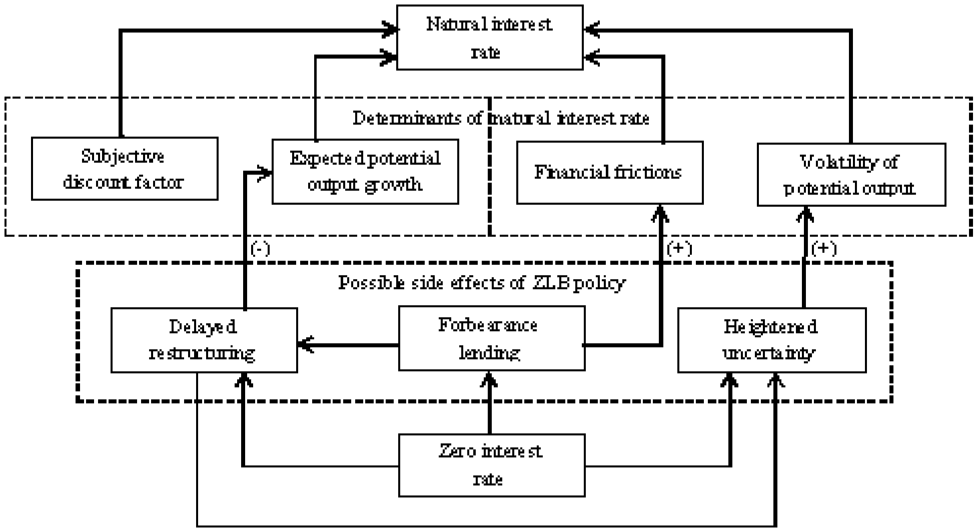
Jiménez G., Ongena S., Peydró J. L., Saurina J. (2012) "Credit Supply and Monetary Policy: Identifying the Bank Balance-Sheet Channel with Loan Applications." *American Economic Review.* 102(5): 2301-2326

Jiménez G., Ongena S., Peydró J. L., Saurina J. (2014) "Hazardous Times for Monetary Policy: What Do Twenty-Three Million Bank Loans Say About the Effects of Monetary Policy on Credit Risk-Taking?" *Econometrica*. 82(2): 463-505

Jung T., Teranishi Y., Watanabe T. (2005) „Optimal Monetary Policy at the Zero-Interest-Rate Bound", *Journal of Money, Credit and Banking* 37(5): 813-835
Kannan P, Scott A., Terrones M. E. (2013) "From recession to Recovery: How Soon and How Strong?" in: Claessens S. et al. [eds.] (2013a)
Klein P. (2000) „Using the Generalized Schur Form to Solve a Multivariate Linear Rational Expectations Model", *Journal of Economic Dynamics and Control* 24: 1405-1423.
Kobayashi K. (2007) "Payment Uncertainty and the Productivity Slowdown." *Macroeconomic Dynamics*. 11(2): 231-248
Krippner L. (2014) "Documentation for United States Measures of Monetary Policy." *Reserve Bank of New Zealand and Centre for Applied Macroeconomic Analysis.* September
Laeven L., Valencia F. (2013) "Systemic Banking Crisis." in: Claessens S. et al. [eds.] (2013)
Laubach T., Williams J. C. (2003) "Measuring the Natural rate of Interest." *Review of Economics and Statistics.* 85(4): 1063-1070
Lazear E., Spletzer R. (2012) "Hiring, Churn and the Business cycle." *American Economic Review.* 102(3): 575-79
Levin A., Lopez-Salido D., Nelson E., Yun T. (2010) "Limitations on the Effectiveness of Forward Guidance at the Zero Lower Bound." *International Journal of Central Banking* 6(1): 143-189
Levine P., McAdam P., Pearlman J. (2008) "Quantifying and sustaining welfare gains from monetary commitment." Journal of Monetary Economics. 55(7): 1253-1276
Maddaloni A., Peydró J. L. (2013) "Monetary Policy, Macroprudential Policy, and Banking Stability: Evidence from the Euro Area" *International Journal of Central Banking*. 9(1): 121-169
Meltzer A. H. (2014) "Slow Recovery with Low Inflation." Book Chapters, in: Baily M. N., Taylor J. B. (ed.), *Across the Great Divide: New Perspectives on the Financial Crisis*. Chapter 8. Stanford: Hoover Institution, Stanford University
Mian A., Sufi A. (2011) "House Prices, Home Equity-Base Borrowing, and the U.S. Household Leverage Crisis." American Economic Review. 101(5): 2132-2156
Nakov A. (2008) "Optimal and simple monetary policy rules with zero floor on the nominal interest rate." *International Journal of Central Banking.* 4(2): 73-127
Nishimura K., Nakajima T., Kiyota K., (2005) "Does the natural selection mechanism still work in severe recessions? Examination of the Japanese economy in the 1990s." *Journal of Economic Behavior and Organization*, 58(1), 53-78
Peek J., Rosengren E. S. (2005) "Unnatural selection: perverse incentives and the misallocation of credit in Japan" *American Economic Review* 95(4): 1144-1166
Pescatori A., Turunen J. (2015) "Lower for Longer: Neutral Rates in the Unites States." *IMF Working Paper*. 15/135
R3 (2013) *Are zombies really attacking the UK economy?* London: Rescue, Recovery, and Renewal (Association of Business Recovery Professionals)
Reinhart C. M., Reinhart V. R., Rogoff K. S. (2012) "Public Debt Overhangs: Advanced-Economy Episodes Since 1800." *Journal of Economic Perspectives.* 26(3): 69–86
Rajan R. G. (2005) "Has financial development made the world riskier?" *NBER Working Papers.* 11728
Schmitt-Grohé S., Uribe M. (2010) "Liquidity Traps: An Interest-Rate-Based Exit Strategy". *NBER Working Paper.* 16514
Schmitt-Grohé S., Uribe M. (2012) " The Making Of A Great Contraction With A Liquidity Trap and A Jobless Recovery." *NBER Working Paper.* 18544
Sekine T., Kobayashi K., Saita Y. (2003) "Forbearance Lending: The Case for Japanese Firms". *Monetary and Economic Studies.* 21(2): 69-92

Simons H. C. (1936) “Rules Versus Authorities in Monetary Policy.” *Journal of Political Economy*. 44(1): 1-30
Smets F., Wouters R. (2002) “Openness, imperfect exchange rate pass-through and monetary policy”, *Journal of Monetary Economics* 49: 947-981.
Smets F., Wouters R. (2003) “An estimated Dynamic Stochastic General Equilibrium model of the euro area”, *Journal of the European Economic Association* 1(5): 1123-1175.
Smets F., Wouters R. (2007) “Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach.” *American Economic Review*. 97(3): 586-606
Stock J. H., Watson M. W. (2012)”Disentangling the Channels of the 2007-09 Recession” Brookings Papers on Economic Activity. 44(1): 81-156
Summers L. H. (2014) “U.S. Economic Prospects: Secular Stagnation, Hysteresis, and the Zero Lower Bound.” *Business Economics*. 49(2): 65-73
Summers L. H. (2015) “Demand Side Secular Stagnation.” *American Economic Review*. Papers and Proceedings. 105(5): 60-65
Swanson E. T. (2015) “Measuring the Effects of Unconventional Monetary Policy on Asset Prices.” *Paper presented at the 19th Annual Conference of Central Bank of Chile “Monetary Policy through Asset Markets: Lessons from Unconventional Measures and Implications for an Integrated World*. Santiago de Chile. November 19-20
Taylor A. M. (2012) “The Great Leveraging.” *NBER Working Paper*. 18290
Taylor J. B. (2009), *Getting off track: How government actions and interventions caused, prolonged, and worsened the financial crisis,* Stanford: Hoover Institution Press
Taylor J. B. (2014) “Causes of the Financial Crisis and the Slow Recovery: A Ten-Year Perspective,” Book Chapters, in: Baily M. N., Taylor J. B. (ed.), *Across the Great Divide: New Perspectives on the Financial Crisis*. Chapter 3. Stanford: Hoover Institution, Stanford University
Wälti S. (2012) “Trust no more? The impact of the crisis on citizens' trust in central banks.” *Journal of International Money and Finance.* 31(3): 593-605.
Walsh C. E. (2009) “Using monetary policy to stabilize economic activity”. *Paper prepared for the Jackson Hole Symposium on Financial Stability and Macroeconomic Policy*. May 18
White W. R. (2010) “The Mayekawa Lecture: Some Alternative Perspectives on Macroeconomic Theory and Some Policy Implications.” *Monetary and Economic Studies*. 28(2012): 35-58
Wieland V., Wolters M. (2011) “The Diversity of Forecasts from Macroeconomic Models of the U.S. Economy.” *Economic Theory*. 47(2-3): 247-292
Williams J. C. (2015) “The Decline in the Natural Rate of Interest.” *Manuscript based on the presentation for the NABE panel “The Outlook for the U.S. and Global Economy: Headwinds, Tailwinds and Whirlwinds” on January 3*. March
Woodford M. (1999) „Optimal Monetary Policy Inertia”, *Proceedings,* Federal Reserve Bank of San Francisco
Woodford M. (2003) *Interest and Prices*. Princeton: Princeton University Press
Woodford M. (2012) “Methods of Policy Accommodation at the Interest-Rate Lower Bound.” *Paper presented at the Jackson Hole Symposium “The Changing Policy Landscape.”* August 30 – September 1
Woodford M. (2015) “Quantitative Easing and Financial Stability.” *Paper presented at the 19th Annual Conference of Central Bank of Chile “Monetary Policy through Asset Markets: Lessons from Unconventional Measures and Implications for an Integrated World*. Santiago de Chile. November 19-20
Yellen J. L. (2015) “Normalizing Monetary Policy: Prospects and Perspectives.” *Speech delivered at “The New Normal Monetary Policy,” a research conference sponsored by the Federal Reserve Bank of San Francisco, San Francisco, California*. March 27

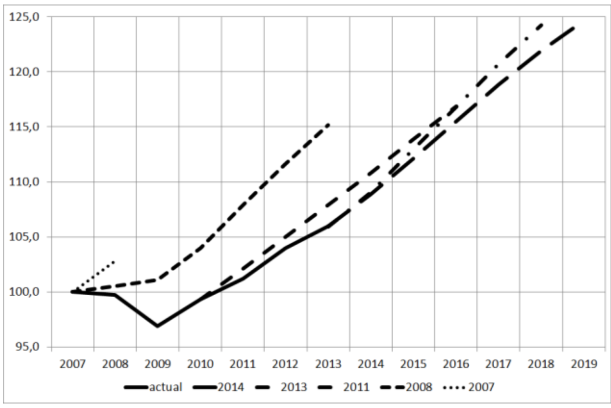
Diagram 1. Impact of possible side effects of ZLB policy on natural interest rate



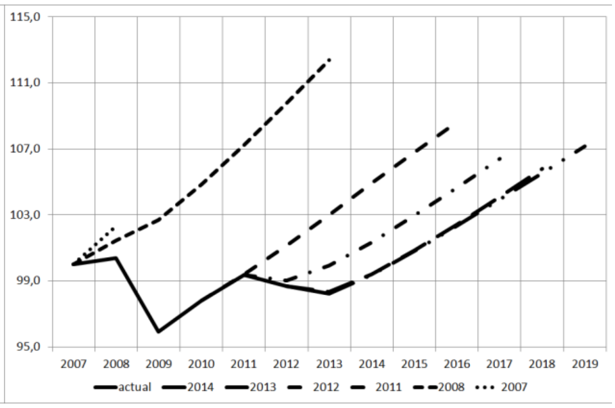
Source: Authors. *Note:* The diagram combines determinants of natural interest rate (upper dashed box) with possible side effects of zero interest rate (lower dashed box). Left part of upper dashed box includes two determinants whose rise increases natural interest rate, while right part of upper dashed box includes two determinants of opposite effect on natural interest rate. Sign minus in the bracket indicates a negative impact of given side effect of zero interest rate on given determinant of natural interest rate, while sign plus in the bracket points out to a positive relationship. The diagram shows that zero interest rate can lead to delayed restructuring, forbearance lending and heightened uncertainty. Delayed restructuring lowers expected potential output growth, forbearance lending strengthens financial frictions and heightened uncertainty translates into larger volatility of potential output. Given that natural interest rate is increasing function of potential output growth and decreasing function of financial frictions and volatility of potential output, every type of possible side effects of zero interest rate leads to a lower natural interest rate.

Figure 1. IMF GDP forecasts generated in the years 2007-2014 and actual GDP growth path (2007-2013)

a: United States



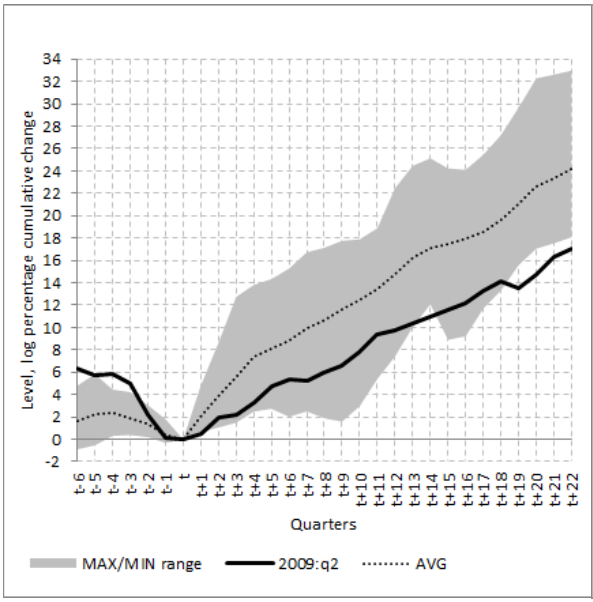
b: Euro area



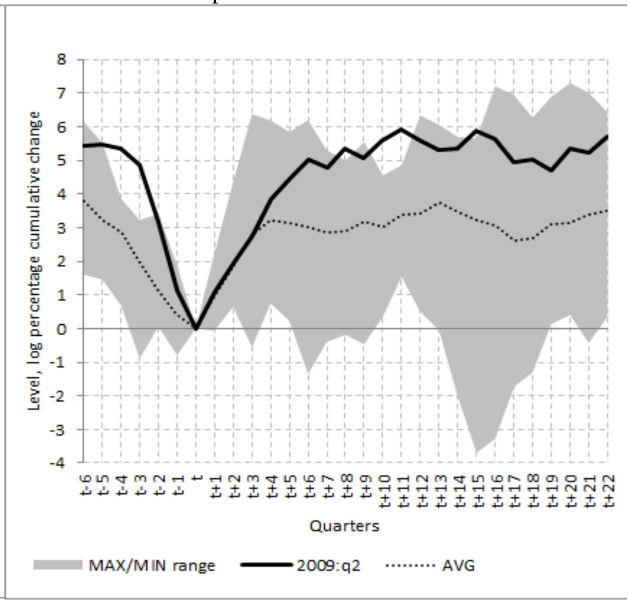
Source: IMF WEO database, April 2007, 2008, 2011, 2013 and 2014. *Note:* This figure represents actual (solid line) and forecasted (dotted lines) GDP growth paths in the United States (a) and Euro area (b). It shows that actual GDP dynamics was turned out to be poorer than expected. 2009, 2010 and 2012 forecasts for the United States and 2009 and 2010 forecasts for the Euro area also indicated faster GDP growth than actually recorded. They are not included in the graph to make it easier to read (they crossed with other forecasts).

Figure 2. Recovery after the Great Recession in the United States and previous recoveries since the second world war

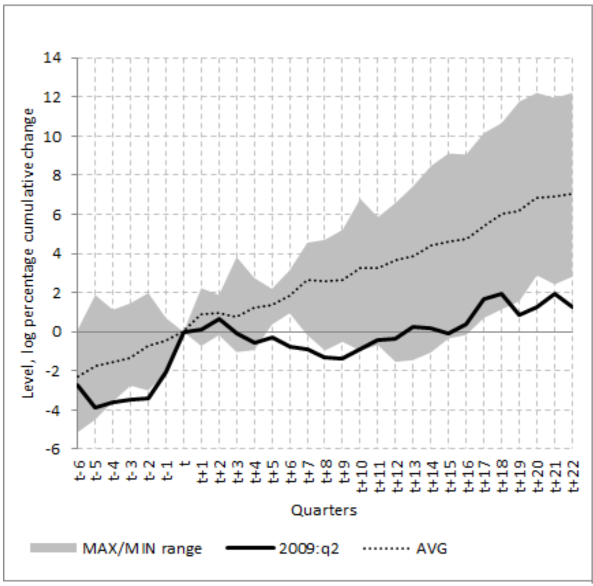
a: GDP



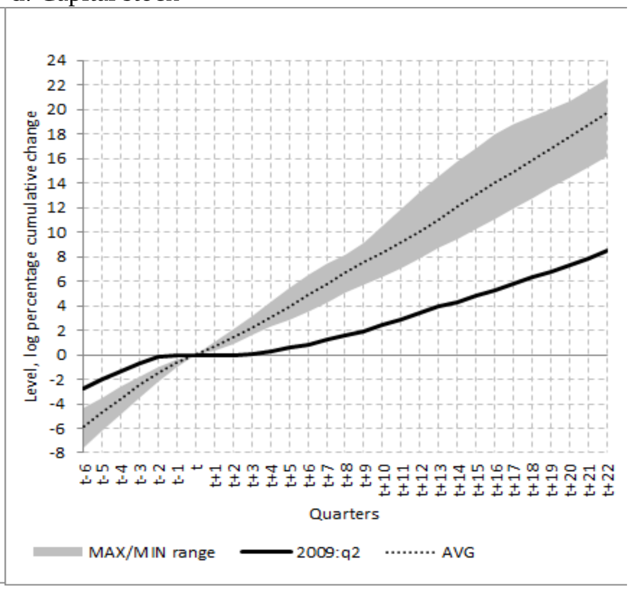
b: Utilization of capital and labour



c: TFP

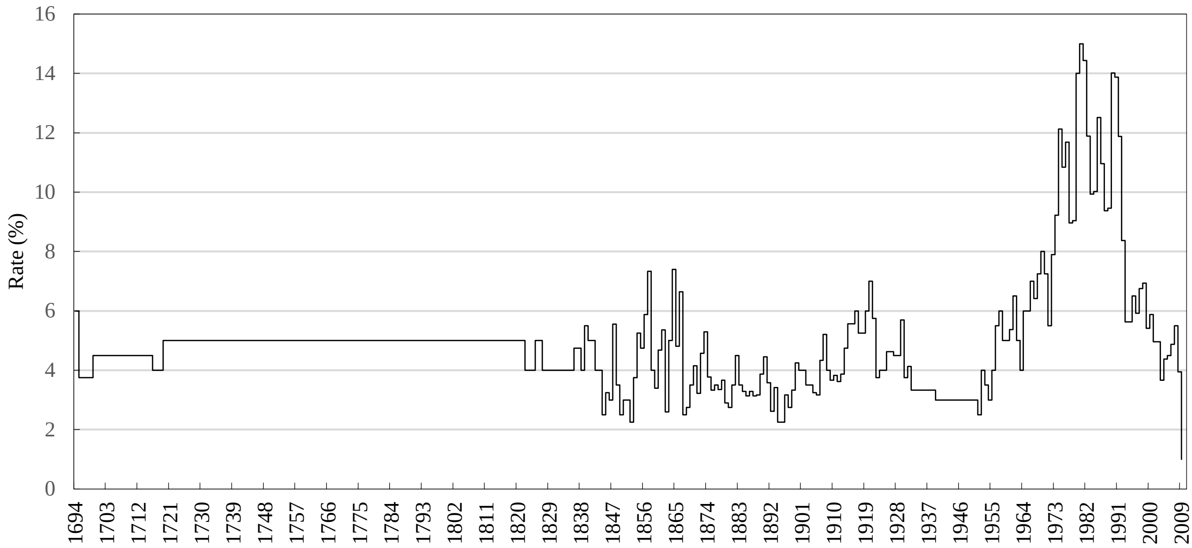


d: Capital stock



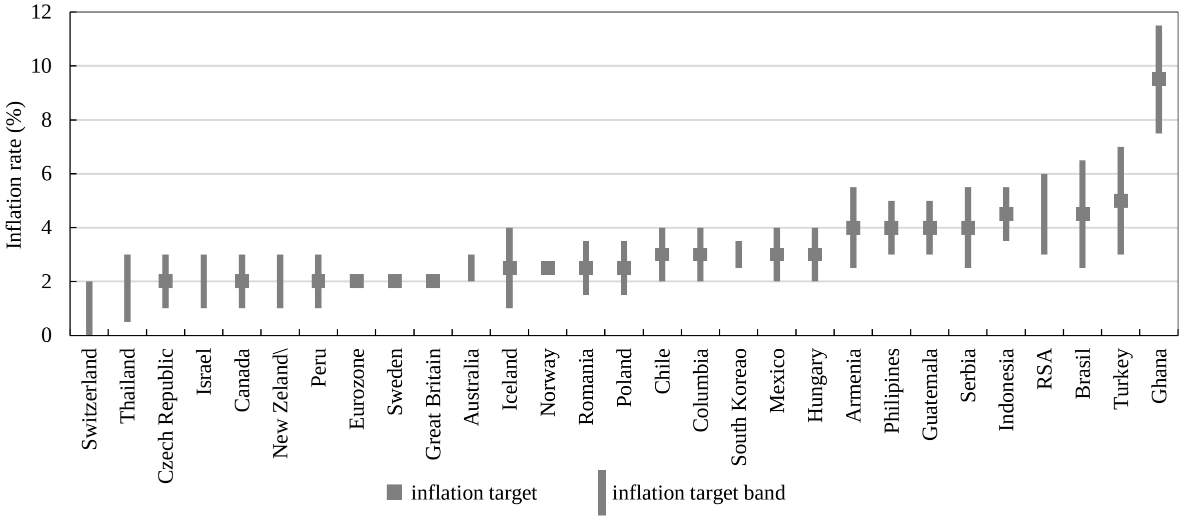
Source: NBP Economic Institute, based on Fernald (2014). *Note:* This figure reports cumulative change of GDP and its main components in the United States after the Great Recession and previous recoveries since the second world war. End of 10 recessions considered is dated in accordance with the NBER. In particular the second quarter 2009 is taken as the end of the Great Recession. The evaluation of utilization of capital and labor follows Basu et al. (2006 and 2013) and TFP data are utilization-adjusted. More details on computations' methodology are provided by Fernald (2014).The horizontal axis represents subsequent quarters, where the end of recession is labeled as *t*. The vertical axis represents log percentage cumulative change of respective variable. The solid line depicts the Great Recession. The dotted line shows the average values while the grey area minimum and maximum values for the previous recoveries. The respective panels shows that though recovery of the US economy has been sluggish by historical standards (a), the utilization of labor and capital has been growing faster than over previous recoveries (b). In contrast, growth in productivity (c) and in capital stock (d) has been very slow.

Figure 3. Bank of England base rate in the period of 1694-2009



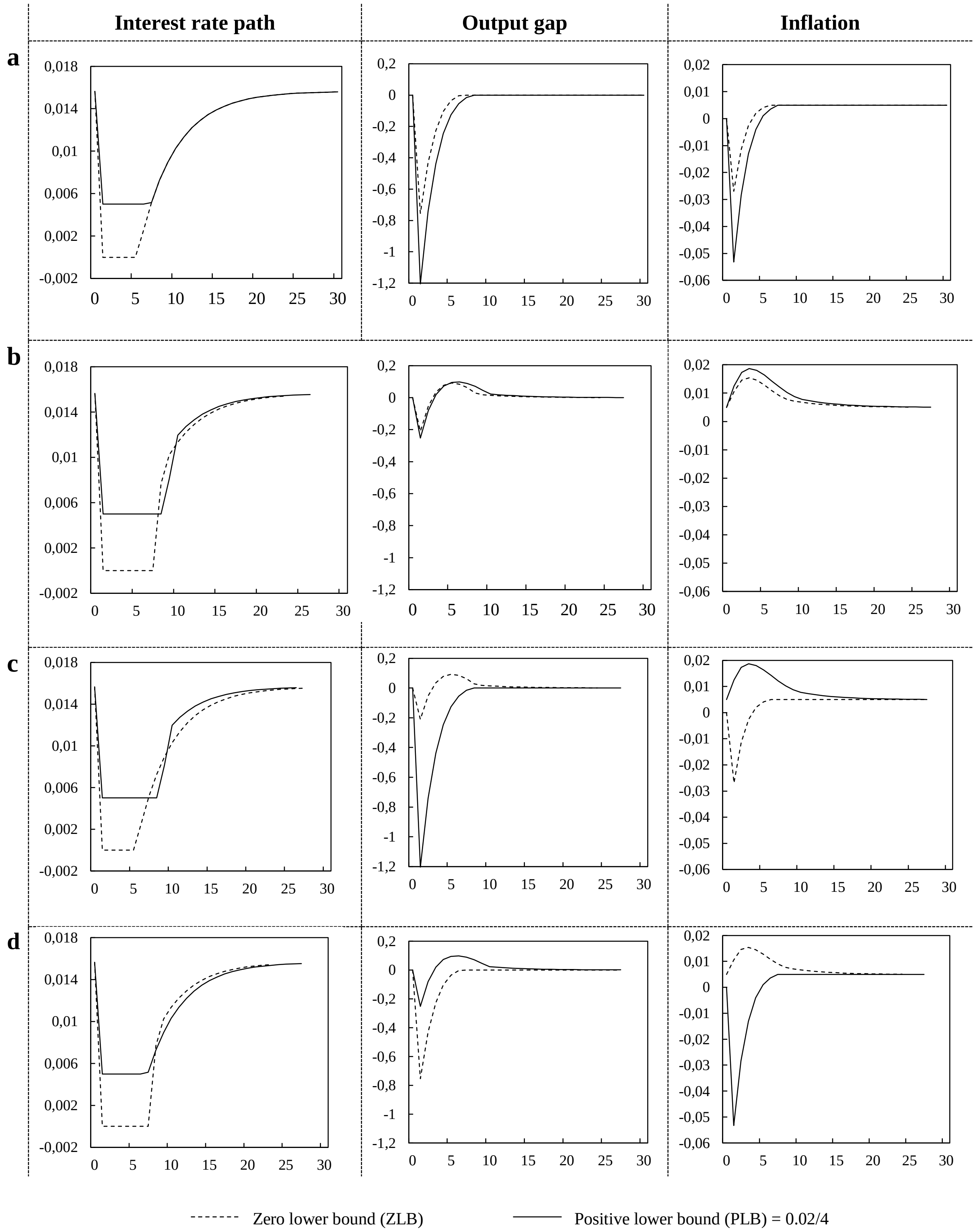
Source: Bank of England. *Note:* This figure reports the base rate of the Bank of England during the period 1694-2009. Data refer to bank rate (for 1694-1972), minimum lending rate (for 1972-1981), minmum band 1 dealing rate (for 1981-1996), repo rate (for 1997-2005) and official bank rate (for 2006-2009). Bank Rate, Minimum Lending Rate, Repo Rate and Official Bank Rate are interest rates. The Minimum Band 1 Dealing Rate is discount rate and refers to the minimum published rate at which the Bank discounted bills to relieve money market shortages (excluding late assistance and repurchase and sale agreements).The figure shows that before the Great Recession the rate has been never set below 2% and its average value amounted to 5.1%.

Figure 4. Inflation targets and inflation targets bands in selected countries



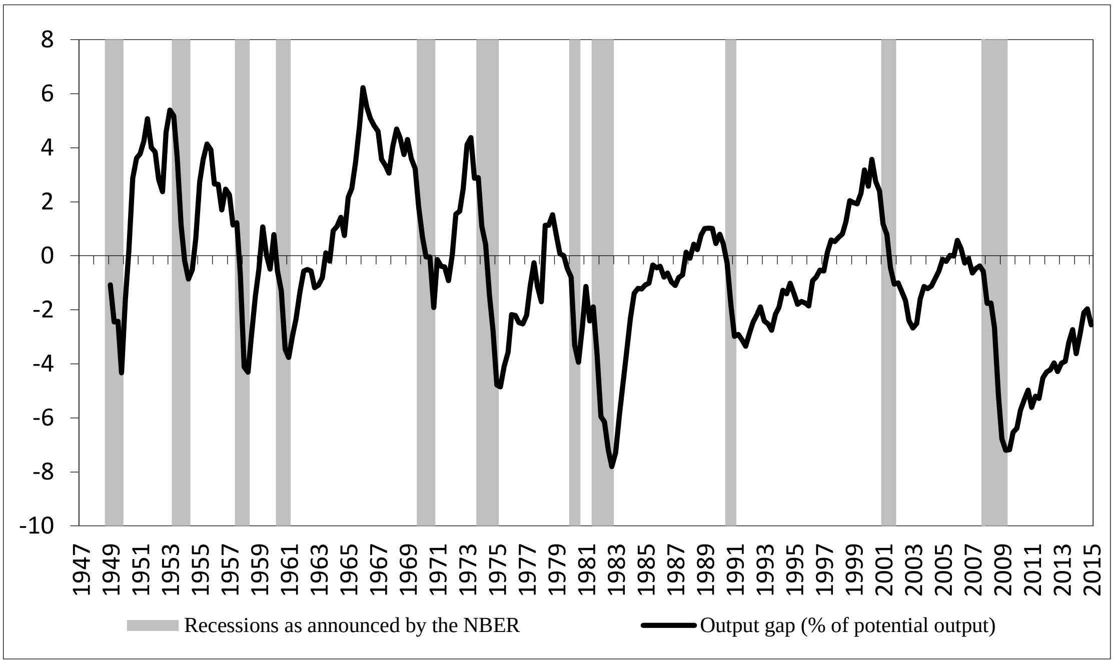
Source: NBP Economic Institute, based on respective central banks' web pages. *Note:* This figure depicts inflation targets of central banks which have introduced direct inflation targeting as monetary policy strategy. It shows that 2% is the level matching inflation targets most frequently seen in advanced economies.

Figure 5. Interest rate, output gap and inflation under various combinations of ZLB and PLB policies:



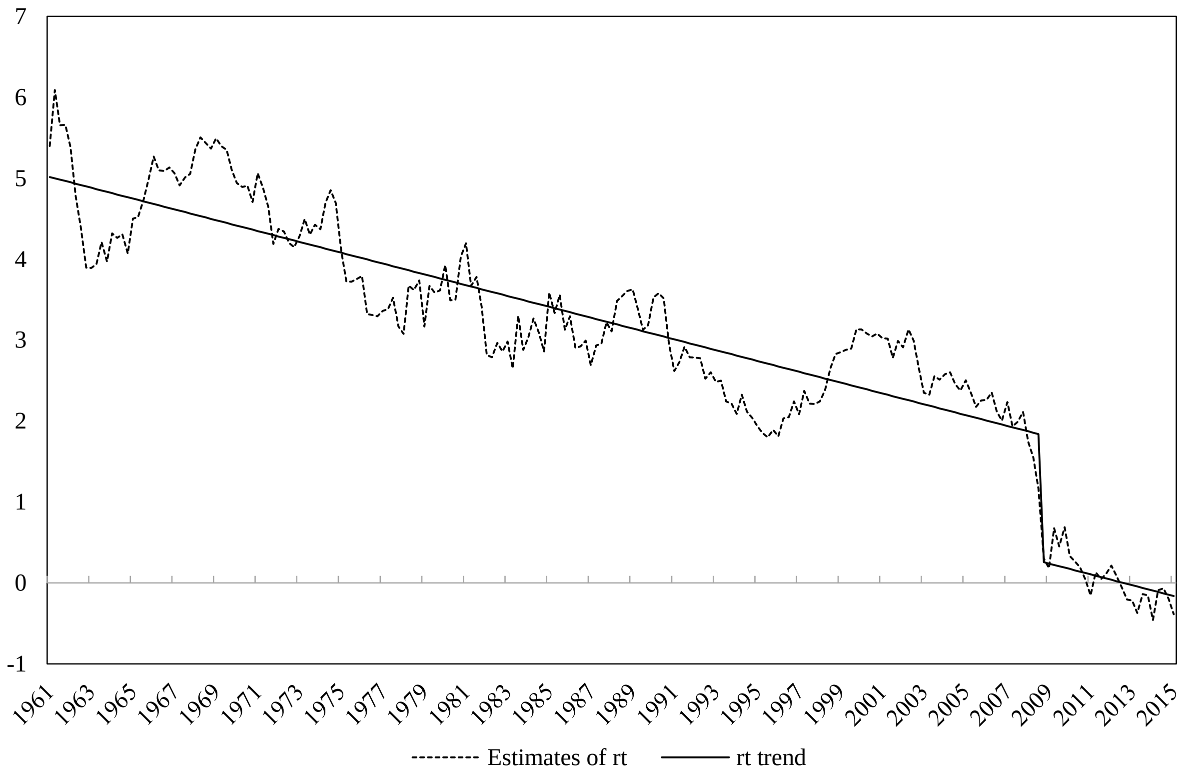
Source: Authors. *Note:* This figure compares the model's results for interest rate, output gap and inflation.The vertical axis represents the steady state value of respective variable for t=0 and then their deviation from the steady state. The horizontal axis depicts the quarters. Four combinations of ZLB and PLB policies varying in terms of their credibility are considered: (a) ZLB and PLB under discretion; (b) ZLB and PLB under commitment; (c) ZLB under discretion and PLB under commitment; (d) ZLB under commitment and PLB under discretion.

Figure 6. Output gap in the United States



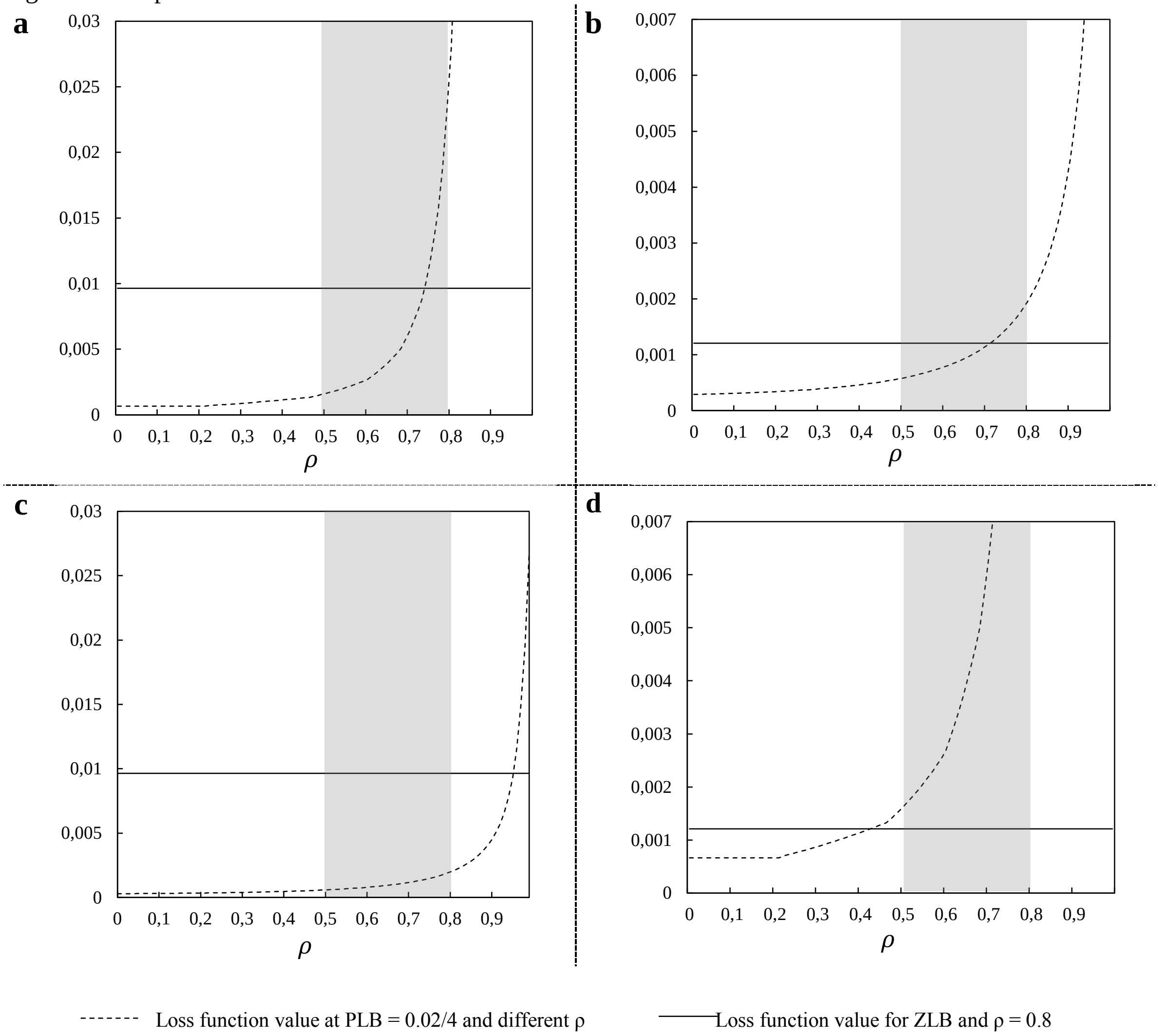
Source: NBP Economic Institute, based on data from BEA and CBO. *Note*: This figure presents output gap in the United States over q1 1949: q1 2015. It is expressed in % of potential output. Data on potential output and GDP are taken from CBO and BEA respectively. Data on GDP for q1 2015 is its second estimate. Grey areas represent recessions as announced by the NBER. The figure shows that output gap closing after the Great Recession has been slower than after any previous recession after the second world war. Note that this slowdown has taken place in spite of a clear deceleration of potential output growth. Since the end of the Great Recession potential output has been growing on average by 1.3% per year, while over previous recoveries its average growth amounted to 3.2%. Note also that although the output gap after the Great Recession was very deep, it wasn't the deepest ever.

Figure 7. Estimates of r_t and shift in its trend after outburst of global crisis



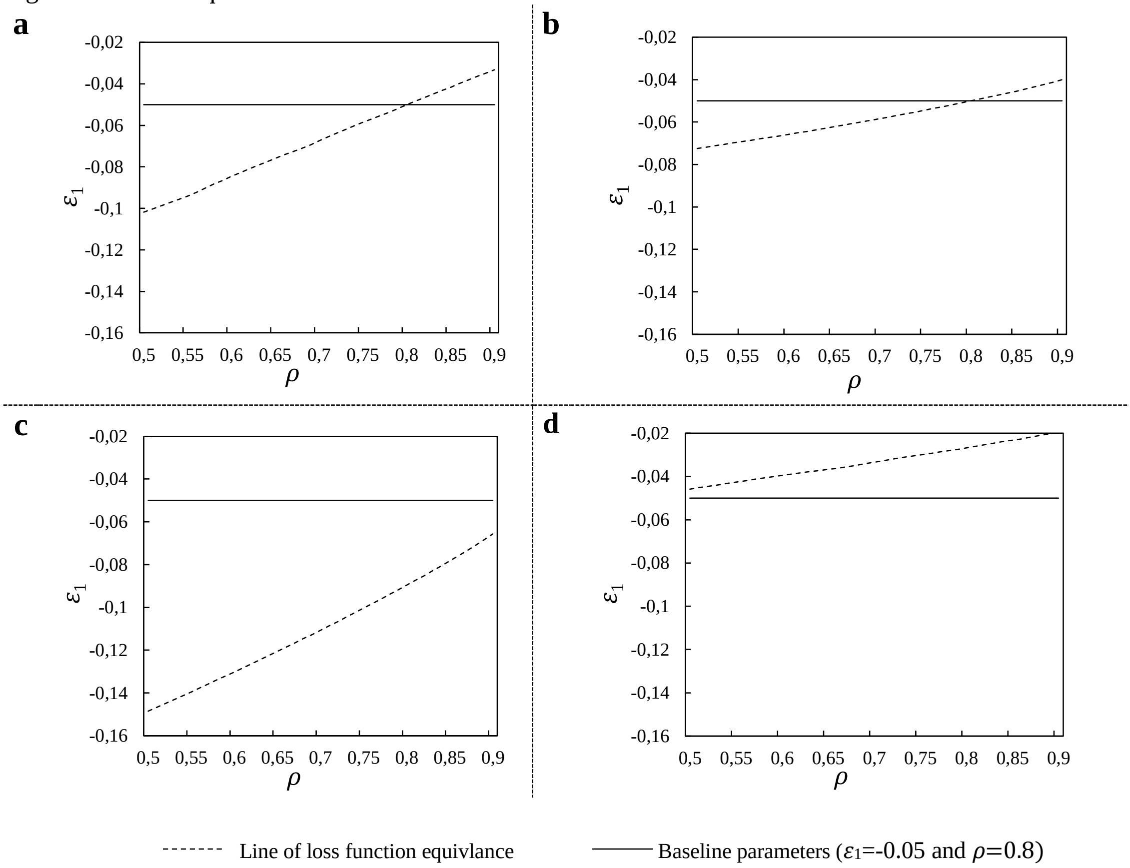
Source: Authors. *Note*: This figure shows updated estimates of r_t from Laubach and Williams (2003) and its trend obtained from the equation $\widehat{r_t} = \hat{\alpha}_0 + \hat{\alpha}_1 t + \hat{\alpha}_3 crisis\_dummy_t$, where $crisis\_dummy_t = 1$ for the quarters q4 2008: q1 2015. Estimates of $r_t$are taken from the web site: http://www.frbsf.org/economic-research/files/Laubach_Williams_updated_estimates.xlsx, Estimates of $\hat{\alpha}_3$ which equals -1,57 and is statistically significant at 1% level, confirms a downward shift of trend in r_t after Q4 2008 when Fed funds rate was cut to near zero.

Figure 8. Comparison of loss function values between PLB and ZLB.



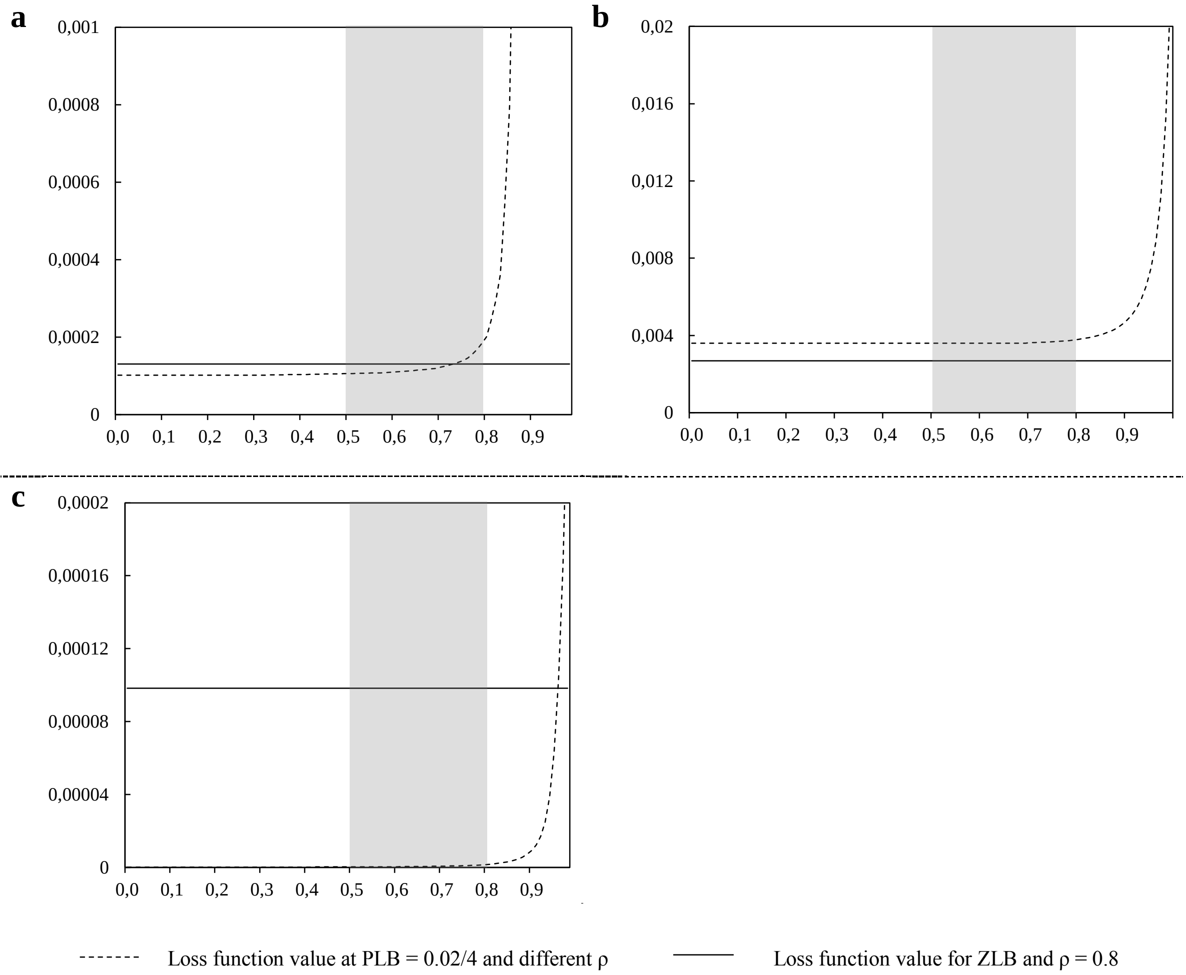
Source: Authors. *Note*: This figure reports loss function values for PLB = 0.02/4 and different autocorrelation coefficient (ρ) of a schock to natural interest rate. The values are compared with loss function value calculated for ZLB and baseline ρ=0.8. The vertical axis represents loss function while horizontal axis autocorrelation coefficient (ρ). The lowest value of ρ covered by the grey area represents the lowest value of this coefficient considered in the literature on the ZLB, while the highest value equals the baseline calibration in the paper. Four combinations of ZLB and PLB policies varying in terms of their credibility are considered: (a) ZLB and PLB under discretion; (b) ZLB and PLB under commitment; (c) ZLB under discretion and PLB under commitment; (d) ZLB under commitment and PLB under discretion.

Figure 9. Line of equivalent loss under PLB:



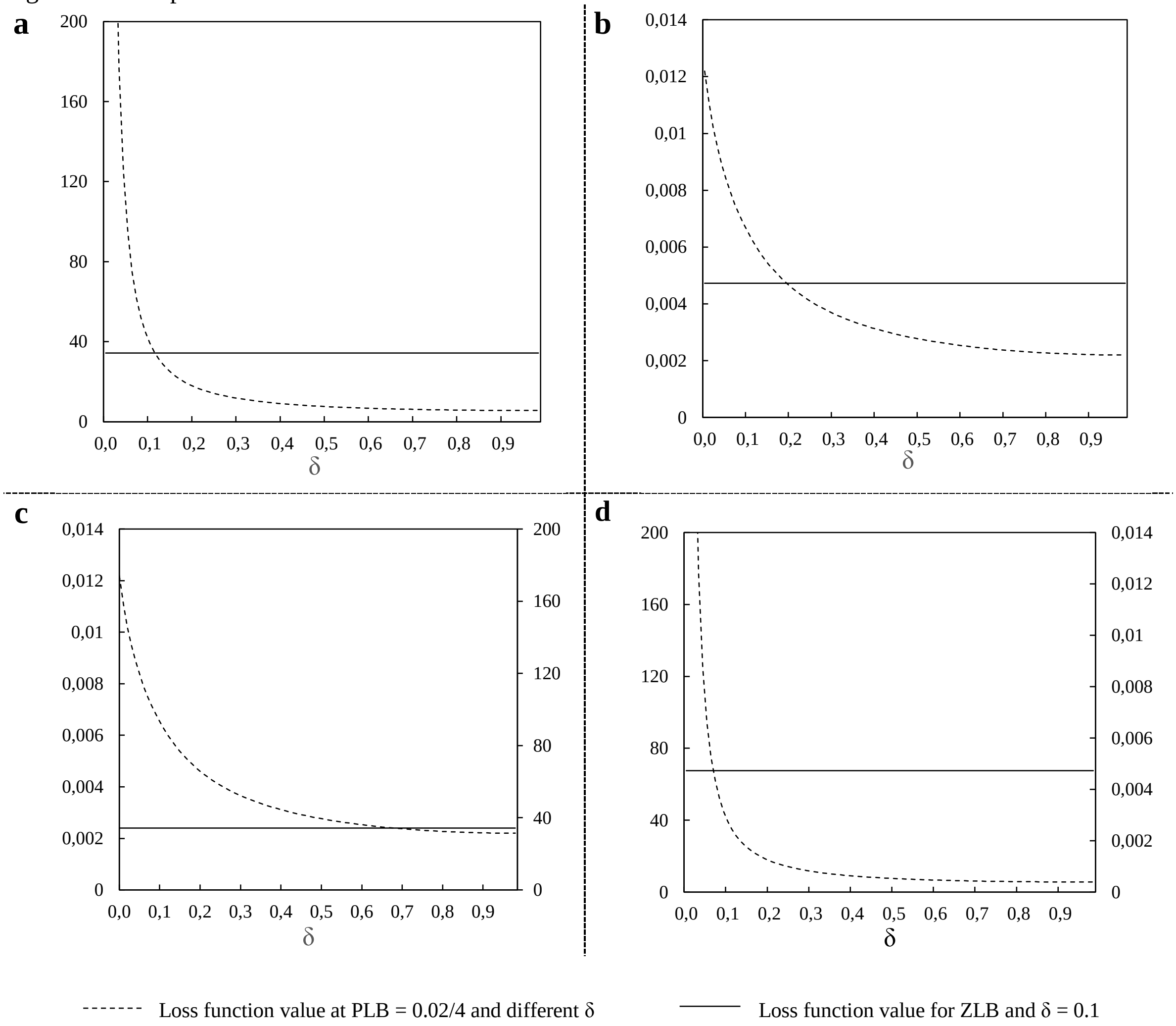
Source: Authors. *Note*: This figure reports combinations of ε_1 and ρ which produce equal values of the loss function for PLB=0.02/4 (calculated for a given combination of ε_1 and ρ) and for ZLB (calculated for baseline combination. ε_1=-0.05 and ρ=0.8). The given combination equalize possible costs of faster restructuring due to PLB policy (as compared to ZLB case) with possible gains stemming from faster shock absorbtion (faster return of natural interest rate to its steady state level). The costs are expressed in terms of initial shock to natural interest rate and are shown as the difference beetwen baseline ε_1=-0.05 (solid line) and ε_1 value for a given ρ (dotted line). Four combinations of ZLB and PLB policies varying in terms of their credibility are considered: (a) ZLB and PLB under discretion; (b) ZLB and PLB under commitment; (c) ZLB under discretion and PLB under commitment; (d) ZLB under commitment and PLB under discretion.

Figure 10. Comparison of loss function values between PLB and ZLB. Robustness check.



Source: Authors. *Note*: This figure reports loss function values for PLB = 0.02/4 and different autocorrelation coefficient (ρ) of a schock to natural interest rate. The values are compared with loss function value calculated for ZLB and baseline ρ=0.8. The vertical axis represents loss function while horizontal axis autocorrelation coefficient (ρ). The lowest value of ρ covered by the grey area represents the lowest value of this coefficient considered in the literature on the ZLB, while the highest value equals the baseline calibration in the paper. Four combinations of ZLB and PLB policies varying in terms of their credibility are considered: (a) ZLB and PLB under discretion; (b) ZLB and PLB under commitment; (c) ZLB under discretion and PLB under commitment. The combinations are calibrated as follows. In the case (a) potential GDP growth rate ($y_{t+1}^P - y_t^P$) is assumed at 4%, trend inflation ($\bar{\pi}$) at 4%, Frisch elasticity of labour supply (φ) at 5, elasticity of substitution between goods varieties (ε) at 10, Calvo probability (θ) at 0,9. In the case (b) $y_{t+1}^P - y_t^P$ is assumed at 4%, $\bar{\pi}$ at 4%, φ at 5, ε at 1,1, θ at 0,4. In the case (c) $y_{t+1}^P - y_t^P$ is assumed at 4%, $\bar{\pi}$ at 4%, φ at 0,1, ε at 10, θ at 0,9. Parameter values are selected so as to get a highly reduced value of break-even ρ. The combination (d) (where ZLB policy is under commitment while PLB policy is discretionary) is not analyzed because it implies already under the baseline calibration the break-even ρ out of the range considered in the literature on the ZLB (cf. Figure 7, panel (d)).

Figure 11. Comparison of loss function values between PLB and ZLB. Alternative definition of shock.



Source: Authors. *Note*: This figure reports loss function values for PLB = 0.02/4 and different conditional probabilities (δ) of reversion of natural interest rate to the steady state value in each period. The definition of shock follows Eggertsson and Woodford (2003). The values are compared with loss function value calculated for ZLB and baseline δ=0.1. The vertical axis represents loss function values while horizontal axis conditional probability (δ). In panels (c) and (d) left hand axis depicts loss function values for PLB policy, while right hand exis – for ZLB policy. Four combinations of ZLB and PLB policies varying in terms of their credibility are considered: (a) ZLB and PLB under discretion; (b) ZLB and PLB under commitment; (c) ZLB under discretion and PLB under commitment; (d) ZLB under commitment and PLB under discretion.

Table 1. Baseline calibration of the model's parameters used in the simulations

Parameter	Value	Source
β	0.99	Woodford (1999)
σ	0.157	Woodford (1999)
$1-\alpha$	0.7	Smets and Wouters (2003)
ε	3	Smets and Wouters (2003)
φ	0.25	Smets and Wouters (2002)
θ	0.7505	implied from other parameter values and Woodford (1999)
ρ	0.8	Adam and Billi (2006, 2007)
ϵ_1	0.05	Levin et al. (2010)
δ	0.1	Eggertsson and Woodford (2003)
$y_{t+1}^P - y_t^P$	$0.02/4$	based on Penn's World Tables
$\bar{\pi}$	$0.02/4$	Authors
PLB	$0.02/4$	Authors

Source: Authors

Table 2. Sensitivity of break-even ρ to changes in the persistence and size of shock to natural interest rate

Panel **A**	ρ used in ZLB model	0,5 (1,000)	0,55 (1,159)	0,6 (1,357)	0,65 (1,609)	0,7 (1,943)	0,75 (2,409)	0,8 (3,106)	0,85 (4,265)	0,9 (6,579)
Break-even ρ	(a) ZLB and PLB under discretion	0,324 (0,615)	0,377 (0,711)	0,475 (0,931)	0,533 (1,102)	0,605 (1,379)	0,667 (1,712)	0,737 (2,271)	0,803 (3,159)	0,868 (4,896)
	(b) ZLB and PLB under commitment	0,257 (0,510)	0,339 (0,641)	0,416 (0,790)	0,493 (0,980)	0,565 (1,214)	0,637 (1,537)	0,708 (2,007)	0,779 (2,775)	0,85 (4,265)
	(c) ZLB under discretion and PLB under commitment	0,649 (1,603)	0,684 (1,825)	0,744 (2,344)	0,797 (3,055)	0,851 (4,296)	0,902 (6,720)	0,952 (14,091)	0,994 (115,178)	
	(d) ZLB under commitment and PLB under discretion					0,22 (0,458)	0,308 (0,589)	0,421 (0,801)	0,512 (1,035)	0,605 (1,379)

Panel **B**	$\epsilon_1$used in ZLB and PLB	-0.02	-0.03	-0.04	-0.05	-0.06	-0.07	-0.08	-0.09	-0.1
Break-even ρ	(a) ZLB and PLB under discretion		0,628 (1,490)	0,711 (2,032)	0,737 (2,271)	0,749 (2,398)	0,757 (2,490)	0,762 (2,550)	0,766 (2,600)	0,769 (2,639)
	(b) ZLB and PLB under commitment		0,549 (1,156)	0,668 (1,718)	0,708 (2,007)	0,729 (2,193)	0,742 (2,323)	0,751 (2,421)	0,757 (2,490)	0,762 (2,550)
	(c) ZLB under discretion and PLB under commitment		0,8 (3,106)	0,843 (4,059)	0,92 (8,313)	0,952 (14,091)	0,969 (22,011)	0,982 (38,161)	0,992 (86,296)	0,999 (692,801)
	(d) ZLB under commitment and PLB under discretion			0,347 (0,655)	0,421 (0,801)	0,445 (0,856)	0,449 (0,866)	0,453 (0,875)	0,456 (0,883)	0,459 (0,890)

Source: Authors. *Note:* This table displays the values of autocorrelation coefficient of a shock to natural interest rate (ρ) which equalizes loss function for PLB=0.02/4 and ZLB (break-even ρ). The brackets report shock half – lives, implied by respective values of autocorelation coefficient. Simulations for other PLB's values from the range from 0 to 2% are available upon request. Panel **A** shows break-even ρ calculated for variuos ρ in ZLB (from 0.5 to 0.9 as indicated by the table header) and four types of ZLB and PLB policies varying in terms of their credibility (as described by **a-d**). Panel **B** shows break-even ρ calculated for various levels of the shock to natural interest rate (ϵ_1) in PLB and ZLB (from -0.02 to -0.1 as indicated by the table header) and four types of ZLB and PLB policies varying in terms of their credibility (as described by **a-d**). Lack of value for particular crossection indicates that break-even ρ in this case would have to be lower than 0 or higher than 1 in order to equalize PLB and ZLB loss function.

Table 3. Robustness check of the findings to changes in the model's calibration

Panel **A**	$\boldsymbol{y^P_{t+1} - y^P_t}$ (baseline: $0.02/4$)	0	0.01	0.02	0.03	0.04
Break-even ρ	(a) ZLB and PLB under discretion	0.737	0.737	0.737	0.736	0.733
	(b) ZLB and PLB under commitment	0.709	0.709	0.708	0.707	0.706
	(c) ZLB under discretion and PLB under commitment	0.957	0.955	0.952	0.949	0.947
	(d) ZLB under commitment and PLB under discretion	0.427	0.424	0.421	0.418	0.415

Panel **B**	$\boldsymbol{\bar{\pi}}$ (baseline: $0.02/4$)	0.02	0.03	0.04
Break-even ρ	(a) ZLB and PLB under discretion	0.737	0.732	0.722
	(b) ZLB and PLB under commitment	0.708	0.703	0.696
	(c) ZLB under discretion and PLB under commitment	0.952	0.932	0.908
	(d) ZLB under commitment and PLB under discretion	0.421	0.408	0.38

Panel **C**	$\boldsymbol{\varphi}$ (baseline: 0.25)	0.1	0.25	0.5	1	2	3	5
Break-even ρ	(a) ZLB and PLB under discretion	0.737	0.737	0.737	0.736	0.736	0.736	0.735
	(b) ZLB and PLB under commitment	0.712	0.708	0.702	0.692	0.675	0.658	0.621
	(c) ZLB under discretion and PLB under commitment	0.935	0.952	0.969	0.985	0.997		
	(d) ZLB under commitment and PLB under discretion	0.469	0.421	0.356	0.274			

Panel **D**	$\boldsymbol{\varepsilon}$ (baseline: 3)	0.1	1.1	2	3	5	10	100
Break-even ρ	(a) ZLB and PLB under discretion	0.741	0.739	0.738	0.737	0.735	0.732	0.735
	(b) ZLB and PLB under commitment	0.547	0.69	0.702	0.708	0.714	0.72	0.725
	(c) ZLB under discretion and PLB under commitment			0.977	0.952	0.908	0.842	0.817
	(d) ZLB under commitment and PLB under discretion		0.212	0.323	0.421	0.504	0.587	0.572
Memo	Implied lambda	0.747	0.039	0.016	0.008	0.003	0.001	0.00001

Panel **E**	$\boldsymbol{\theta}$ (baseline: 0.7505)	0.4	0.5	0.6	0.7	0.8	0.9
Break-even ρ	(a) ZLB and PLB under discretion	0.743	0.743	0.741	0.738	0.735	0.731
	(b) ZLB and PLB under commitment	0.661	0.674	0.688	0.702	0.714	0.722
	(c) ZLB under discretion and PLB under commitment				0.983	0.908	0.811
	(d) ZLB under commitment and PLB under discretion				0.303	0.505	0.617

Source: Authors. *Note:* This table displays the values of autocorrelation coefficient of a schock to natural interest rate (ρ) which equalizes loss function for PLB=0.02/4 and ZLB (break-even ρ). Simulations for other PLB's values from the range from 0 to 2% are available upon request. Respective panels show break-even ρ calculated for variuos potential GDP growth rates ($y^P_{t+1} - y^P_t$, from 0.0 to 0.04 as indicated by the table header of panel **A**), trend inflation ($\bar{\pi}$, from 0.02 to 0.04 as indicated by the table header of panel **B**), Frisch elasticity of labour supply (φ, from 0.1 to 5 as indicated by the table header of panel **C**), elasticity of substitution between goods varieties (ε, from 0.1 to 100 as indicated by the table header of panel **D**) and Calvo probability (θ, from 0.4 to 0.9 as indicated by the table header of panel **E**). For each of the cases four types of ZLB and PLB policies are concidered varying in terms of their credibility (as described by **a-d**). Lack of value for particular crossection indicates that break-even ρ in this case would have to be lower than 0 or higher than 1 in order to equalize PLB and ZLB loss function.