In search for appropriate lower bound.
Zero lower bound vs. positive lower bound under discretion and commitment

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Abstract

We lay a ground for a simple comparison of positive and possible side (adverse) effects of zero interest rate policy (ZLB policy) on welfare. The effects of these two types have been analyzed so far in complete isolation from each other. 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), then 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, even limited side effects of the ZLB policy usually suffices for the PLB policy to pay off in terms of welfare. This is true especially for the case when central bank fails to commit. Only if the ZLB policy was pursued under commitment, while PLB policy was discretionary, would the PLB policy dominance over the ZLB policy, in terms of welfare, require strong side effects of ZLB policy. Otherwise 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. For a given side effects of the ZLB, the larger and the more persistent the shock that makes the ZLB bind, the more likely PLB policy dominance over the ZLB policy. The findings holds for economies with both fast and slow potential output growth, with low and high inflation target, flexible and rigid.

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

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1. Introduction

Until recently, an effective lower bound on interest rate was 2% or more (for details see, Homer and Sylla, 2005). In 20th century, interest rates were kept below that bound virtually only after the Great Depression, during war economy and its withdrawal, occasionally in some centrally planned economies, in Switzerland coping with excessive capital inflows in 1977-1978 and 1996-1999 and in Japan after speculative bubble bursting 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 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 meanwhile became the basic analytical tool for central banks. The NK analytical framework implies that the ZLB is not necessarily a serious constraint on central bank's capability to stabilize economy. In fact, if a central bank is highly credible, then costs of the ZLB are, according to the NK framework, quite limited. The central bank can still stabilize economy by affecting expectations of future interest rates (see, e.g. Walsh, 2009, and the papers that Walsh refers to). However, after the Lehman collapse in 2008, when the ZLB became binding in all major economies, their economic performance turned out to be poorer than expected (see figure 1).

(Figure 1)

Most economists link that disappointing performance either to factors beyond reach of monetary policy, or to central banks' reluctance to rigorously follow prescriptions from 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, even though central banks shifted aggressively to interest rates close to zero, their forward guidance has provided forecasts of likely interest rate path, instead of making the commitment not to respond promptly to future demand pressure.

However, there is a few economists, who warn against monetary policy 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, thwarts capital and labor reallocation. It thus strengthens financial frictions and deter post-crisis restructuring. In turn, Meltzer (2014) and Taylor (2014), among others, contend that 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.[2]

Some evidence supports the minority views. In particular, even though recovery of the US economy has been sluggish by historical standards, the utilization of labor and capital has been growing faster than over previous recoveries. In contrast, growth in productivity and,

1 For the first time the ZLB was analyzed 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 We leave aside the most frequent criticism of extremely accommodative monetary policy, centered on risk misjudgment, excessive risk taking, and asset bubbles 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 which has no slack rather than to one hit by a crisis and struggling to recover, which is focus of interest in this paper

above all, in capital stock (in spite of rapid development of capital intensive shale gas and oil industry) has been very slow (see figure 2).[3]

(Figure 2)

It is hardly possible to settle, with any doubts, which of these two opposite views is correct. Such a settlement is certainly beyond the scope of this paper, which deals with a much less ambitious problem. It evaluates how strong (weak) possible side effects of holding interest rates close to zero would 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. Firstly, we allow the lower bound to be any real number, not only zero. As the baseline case, we consider PLB at 2%. This was the floor for policy rate of Bank of England since its foundation in 1694 until 2009 (see figure 3). Secondly, 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).

(Figure 3)

(Figure 4)

The evaluation comprises two steps. Firstly, 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 of them 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. Secondly, we check how much less persistent a shock under PLB policy would have to be, compared to one dealt with ZLB policy, so that the welfare losses of the PLB did not exceed those incurred under the ZLB.

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

- forbearance lending which strengthens 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 in the equation of natural interest rate, and can inhibit its return after a shock to the steady state.

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 of all, this is the first study which compares 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 vast majority is based on NK models with output gap, inflation, natural interest rate and interest rate only. Second, the extension (by this paper) of otherwise

[3] TFP growth was rapid in the acute phase of the global financial crisis, that is in 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. Its cumulative increase until the end of 2014 amounts to mere 1.3% (cf. Fernald, 2014).

benchmark model to allow trend inflation complicates computations, whereas it does not significantly affect results of the comparison. This leads us to the conjecture that a focus on medium scale NK model would not alter them either, but it would make the computations even more complex. We leave its verification for further research. Even if it is refuted, gradual extension of the framework would facilitate understanding of where possible significant differences in effects of the PLB and ZLB stem from. This would be hardly possible to verify otherwise.

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

Our main findings are as follows.

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

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

Third, 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 possible side effects of the ZLB, however only under the condition that it would be more likely under the ZLB policy than PLB policy.

Fourth, when the above condition is not met, then 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 given side effects of the ZLB policy, PLB policy is more likely to increase welfare, when a shock that makes the ZLB bind, is particularly large and persistent. This result implies that central bank should be particularly cautious about cutting interest rates to zero in circumstances that other papers consider to call for aggressive cuts.

Seventh, all above findings holds for economies with both fast and slow potential output growth, with low and high inflation target, flexible and rigid. Any differences in results between those 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 target, and strong rigidities: nominal and in labor supply, although tough competition.

The paper makes four main contributions to the literature.

Firstly, it studies effects of PLB. The possibility of positive lower bound instead of being zero is noticed in other studies on ZLB (see, e.g. Eggertsson and Woodford, 2003).[4] However, it has only been analysed, if at all, in the context of 'lack of confidence' shock and self-fulfilling deflations (see, e.g. Benhabib et al., 2001; Schmitt-Grohé and Uribe, 2010 or Schmitt-Grohé and Uribe, 2012). We analyze 'fundamental' shock instead, which is extensively used in the literature on ZLB.

Secondly, the paper develops a simple analytical framework, which allows to compare benefits with possible costs of interest rate close to zero and other unconventional monetary policy measures. Both these effects have so far been analysed in complete isolation from each

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

other. We facilitate breaking this isolation and thereby better exploiting knowledge acquired from the above analyses.

Thirdly, the paper puts into question an important policy advice from the literature on the ZLB. From Eggertsson and Woodford (2003) onwards, this literature has unanimously advocated for very aggressive interest rates cuts in response to severe negative shocks or 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 the suggested caution is the risk of side effects of ZLB policy, whereas in some older papers it is a preservation of some powder dry for future emergencies.

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

The remainder of the paper is organized in four sections and an appendix. Section 2 reviews related literature. 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 shock to natural interest rate. Section 3 describes the model used and its calibration. Section 4 provides main findings and verifies their robustness. Section 5 concludes. The appendix including figures and tables follows.

2. Related literature

Our findings relate to that strand of the literature on the ZLB, which envisages '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 natural interest rate, r_t,. Literally interpreted, it means that all of a sudden everybody wants to save more. However, given that natural interest rate may also depend on other variables than discount factor, more sophisticated interpretations are also possible, and indeed they are used. In particular, they have recently been referring to financial frictions (cf., e.g. Eggertsson, 2011). Even though financial frictions are not modelled in versions of NK framework commonly used in analyses of the ZLB, it has been shown elsewhere that NK model with those frictions can be reduced to a form quite similar to its 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 frictions (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 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 interest of economists in the ZLB. After the asset bubble bursting in the early 1990s, troubled Japanese banks were allocating 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 further worsened (Sekine et al., 2003). Banks imposed discipline on viable firms only (Arikawa and Miyajima, 2007). Insolvent firms kept afloat lowered viable firms' profitability, which discouraged their development and entries of new firms (Caballero et al., 2008). Still worse, while support to non-viable firms was maintained, many productive firms, especially new entrants, exited (Nishimura et al., 2005). In industries where non-viable firms were heavily present, they increased their market share (Ahearne and Shinada, 2005). Payment uncertainty discouraged specialization (Kobayashi, 2007). Technology spillovers declined (Fukao, 2013). Political leadership resisted capital and labor 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 labor reallocation increased and prolonged disappointing economic performance of Japan (Nishimura et al, 2005).

Even though the literature in question has been developed far from the mainstream economics, it is likely to bring policy relevant 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). Even though in the UK it was of limited scale, corporate insolvencies remained historically low there, while in early phase 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. 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 thereof prior to the crisis. Correlation between profitability and investment across firms weakened considerably. Share of both product and process innovators decreased (Barnett et al., 2014a and 2014b). In the US, increase in insolvencies after the outburst of the crisis was very short-lived (Deutsche Bank, 2013). Churn decreased significantly (Lazear and Spletzer, 2012). Reallocation not only became less intensive, but also enhanced productivity by 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 suggests 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 recovery when financial crisis burst. In turn, Chen et al (2015) corroborate that the larger and the quicker the private sector deleveraging, the more sizable medium-term output gains. In line with those 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 break the isolation between the literature on the ZLB and possible side effects of very accommodative monetary policy, because all main types of those effects, namely: forbearance lending, delayed restructuring and heightened uncertainty appear, indirectly or even directly, in the natural interest rate equation which is at the center of the literature on the ZLB.

Forbearance lending, facilitated by the ZLB policy, can be considered to inhibit a return of the natural interest rate to the steady state, since it strengthens financial frictions (see

Eq. 1) related to collateral constraints and capital requirements.[5] First, it distorts publicly available signals that help to assess 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 hardly able to deleverage, but this perverse composition of deleveraging firms magnifies problems of information asymmetry. Secondly, forbearance lending forces banks to rely heavily on retained earnings to rebuild their capital. It 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 entire banking sector undergoes restructuring. Hence, the rebuilding of capital takes a long time (additionally prolonged by 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 incentives to delay balance sheet repair, as this delay helps them to meet capital requirements.

Decelerated return of 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 exits of enterprises instead of promoting entries. Secondly, it supports current operations instead of new ones, which could increase productivity of firms continuing operations. Firms in receipt of forbearance have no incentive to restructure because effort put into restructuring would bring benefits to their creditors, not to them. Furthermore, they have to avoid any additional expenses (that restructuring usually requires for some time), as new costs could be considered by banks a signal of actions increasing creditors' losses and thus result in an immediate cut off from funding. This inspires their inaction and leads to betting for resurrection. Thirdly, 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).

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

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 *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 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 losses' recognition and balance sheet's repair (cf. Arrowsmith et al., 2014).[6] Very accommodative monetary policy can also discourage government from reforms enhancing restructuring (Borio, 2014).

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

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

Ultimately, one can consider heightened post crisis uncertainty prolonged by the ZLB policy to be responsible for slower return of natural interest rate to the steady state (see Eq. 4)[7].

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

By delaying post-crisis adjustments, the ZLB policy maintains uncertainty about timing, scope, and effects of restructuring, while limiting scope for reducing uncertainty through information acquisition and processing, as its quality is low.[8] At the same time, high risk persists that it will become obsolete. Even a small negative shock may cease operations of non-viable firm for banks may confound effects of shock with debtor's actions increasing their losses. Still worse, a positive economic development is not at all favorable for such firm 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 turn out to be non-viable or collaborate with non-viable firms. All in all, firms do not know when the structure of the economy will seriously change, and how it will change. However, they should have no doubt that serious changes will come. If the economy had not needed them, there would be no crisis. Unprecedented nature of the ZLB policy contributes to that risk, as signaled in the introduction.

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

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. Previous research on the lower bound for interest rates was based on the standard New Keynesian Phillips Curve, which we has 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:

$$\mathcal{L}_t = \sum_{i=0}^{\infty} \beta^i L_{t+i} \tag{5}$$

with the following one-period loss function L_t:

$$L_t = \pi_t^2 + \lambda y_t^2 \tag{6}$$

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 inflation rate from the steady state. This has no influence on the variance of π^2, and hence on policy ranking according to the loss function values.

Policymakers are constrained by standard behavioral 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 ($\bar{\pi}$):

$$y_t = E_t y_{t+1} - \sigma^{-1}(i_t - E_t\pi_{t+1} - \bar{\pi} - r_t) \tag{7}$$

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

7 However, this relationship is generally neglected (see, e.g. Gali, 2008) for two interrelated reasons. First, until recently only the first order log linearization of the model has been considered. Second, it is usually assumed that the second order terms are small.

8 Non-viable firms kept afloat hinder assessment of financial credibility of any firm and its partners, existing and potential ones.

counterpart under zero steady state[9] (see Ascari, 2004; Bakhshi et al., 2007; Cogley and Sbordone, 2008). A simple quasi-differencing operation allows to present this equation in the following recursive form:

$$\pi_t = \beta_1 E_t \pi_{t+1} + \beta_2 E_t \pi_{t+2} + \kappa_1 y_t + \kappa_2 E_t y_{t+1} \tag{8}$$

whereby the reduced-form parameters in (8) are derived as follows:

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

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

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

$$\kappa_2 = \frac{\left(\overline{\Pi}^{1+\frac{\varphi+\alpha}{1-\alpha}\varepsilon}-1\right)\beta(1-\theta\overline{\Pi}^{\varepsilon-1})(1-\beta\theta\overline{\Pi}^{\varepsilon-1})}{1+\frac{\varphi+\alpha}{1-\alpha}\varepsilon} - \beta\theta\overline{\Pi}^{\varepsilon-1}\kappa_1 \tag{9}$$

The notation for deep parameters used in equation (9) 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. $\overline{\Pi} = 1 + \bar{\pi}$ 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 so as to ensure the consistency between individual reduced-form parameters in extended equation (8).

Minimizing (6) subject to constraints (7) and (8), after skipping the expectation operators (under perfect foresight, as in Jung et al., 2005), implies the following Lagrange function:

$$\begin{aligned} \mathcal{L}_t = \textstyle\sum_{i=0}^{\infty} \beta^i \quad \{ & L_{t+i} + 2\phi_{1,t}[y_t - E_t y_{t+1} + \sigma^{-1}(i_t - E_t\pi_{t+1} - \bar{\pi} - r_t)] + \\ & +2\phi_{2,t}[\pi_t - \beta_1 E_t\pi_{t+1} - \beta_2 E_t\pi_{t+2} - \kappa_1 y_t - \kappa_2 E_t y_{t+1}]\} \end{aligned} \tag{10}$$

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:

$$(i_t - PLB)\phi_{1,t} = 0 \tag{11}$$

$$i_t \geq PLB \tag{12}$$

$$\phi_{1,t} \geq 0 \tag{13}$$

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 zero Lagrange multiplier on IS curve) or binding (which leads to positive loss, i.e. non-fulfilment of equation (7) and positive Lagrange multiplier on IS curve).

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

3.2. Shock definition

We start in period 0 and assume that all variables take their steady state values, i.e. (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 the equation (2), as in Jung et al. (2005). In period 1, a shock of size ϵ_1 occurs that brings the natural interest rate down to a level which renders the lower bound binding ($i_1 = PLB$ and $\phi_{1,1} = 0$):

$$r_1 = \bar{r} + \epsilon_1 \tag{14}$$

This shock is assumed to exhibit serial correlation of order 1 with inertia parameter ρ:

$$r_t = \rho r_{t-1} + (1-\rho)\bar{r} \tag{15}$$

Further shocks are not considered, i.e. equation (15) 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 (10), subject to (11)-(13), or acts under discretion.

3.3. Solution under commitment

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

$$\lambda y_t + \phi_{1,t} - \beta^{-1}\phi_{1,t-1} - \kappa_1\phi_{2,t} - \beta^{-1}\kappa_2\phi_{2,t-1} = 0 \tag{16}$$

$$\pi_t - (\beta\sigma)^{-1}\phi_{1,t-1} + \phi_{2,t} - \beta^{-1}\beta_1\phi_{2,t-1} - \beta^{-2}\beta_2\phi_{2,t-2} = 0 \tag{17}$$

Note that the generalization to positive steady state inflation, as in (8), implies the inclusion of second-order dynamics into the model. This also emerges in (17) as the second lag of 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 (11)-(13). 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 as 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 (7), (8), (16) and (17) for $t = 1, \ldots, T$ with $i_t = PLB$.
2. Equations (8), (16) and (17) for $t = T + 1$ with $\phi_{1,T+1} = 0$, but $\phi_{1,T} > 0$.
3. Equations (8), (16) and (17) 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 (7).

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 (16) to express y_t as a function of $\phi_{2,t}$ and $\phi_{2,t-1}$. After substitution into (8), 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 (17), forms a dynamic system of forward-looking equations that can be cast into matrix form as:

$$\boldsymbol{A}\begin{bmatrix}\pi_{t+2}\\ \pi_{t+1}\\ \phi_{2,t+1}\\ \phi_{2,t}\end{bmatrix}=\boldsymbol{B}\begin{bmatrix}\pi_{t+1}\\ \pi_{t}\\ \phi_{2,t}\\ \phi_{2,t-1}\end{bmatrix} \tag{18}$$

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:

$$\begin{bmatrix}\phi_{2,t}\\ \phi_{2,t-1}\end{bmatrix}=\begin{bmatrix}\gamma_1 & \gamma_2\\ 0 & 1\end{bmatrix}\begin{bmatrix}\phi_{2,t-1}\\ \phi_{2,t-2}\end{bmatrix} \tag{19}$$

The upper block of (19), coupled with (17) – and with the fact that all relevant lags of ϕ_1 are zero in phase 3 – yields the following system of equations:

$$\begin{bmatrix}\pi_t\\ \phi_{2,t}\end{bmatrix}=\begin{bmatrix}-\gamma_1+\beta^{-1}\beta_1 & -\gamma_2+\beta^{-2}\beta_2\\ \gamma_1 & \gamma_2\end{bmatrix}\begin{bmatrix}\phi_{2,t-1}\\ \phi_{2,t-2}\end{bmatrix} \tag{20}$$

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:

$$\begin{bmatrix}\pi_t\\ y_t\\ \phi_{2,t}\end{bmatrix}=\boldsymbol{A_1}\begin{bmatrix}\phi_{2,t-1}\\ \phi_{2,t-2}\end{bmatrix}+\boldsymbol{A_2}\begin{bmatrix}\pi_{t+2}\\ \pi_{t+1}\\ y_{t+1}\end{bmatrix}+\boldsymbol{B_1}[\phi_{1,t}]+\boldsymbol{B_2}[\phi_{1,t-1}] \tag{21}$$

Note that for $t=T+1$, i.e. in phase 2, $\boldsymbol{B_1}$ is equal to zero vector. Also, $\boldsymbol{B_2}=(\lambda+\kappa_1^2)^{-1}\begin{bmatrix}\kappa_1^2(\beta\sigma)^{-1}+\kappa_1\beta^{-1}\\ \kappa_1(\beta\sigma)^{-1}+\beta^{-1}\\ \lambda(\beta\sigma)^{-1}-\kappa_1\beta^{-1}\end{bmatrix}$, $\boldsymbol{A_1}=(\lambda+\kappa_1^2)^{-1}\begin{bmatrix}\kappa_1^2\beta^{-1}\beta_1+\kappa_1\beta^{-1}\kappa_2 & \kappa_1^2\beta^{-2}\beta_2\\ \kappa_1\beta^{-1}\beta_1+\beta^{-1}\kappa_2 & \kappa_1\beta^{-2}\beta_2\\ \lambda\beta^{-1}\beta_1-\kappa_1\beta^{-1}\kappa_2 & \lambda\beta^{-2}\beta_2\end{bmatrix}$ 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 (16) and (17) when the central bank cannot credibly commit to follow the same optimum policy rule in the future. In such 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:

$$\begin{aligned}r_T+\bar{\pi}&\leq PLB\\ r_{T+1}+\bar{\pi}&> PLB\end{aligned} \tag{22}$$

In (22), and per 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 $i_t=r_t+\bar{\pi}$ so as to keep $y_t=\pi_t=0$.

For $t=1,\dots,T$ the model consists of equations (7), (8), along with the constraint equation:

$$i_t=PLB \tag{23}$$

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

$$\begin{aligned}y_{T+1}&=0\\ \pi_{T+1}&=0\\ \pi_{T+2}&=0\end{aligned} \tag{24}$$

3.5. Calibration

Our calibration strategy is to hold our model (and results) as comparable as possible 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. To see this, consider the standard definition of the price level at *t* in the pricesetting model *à la* Calvo:

$$P_t = \left[(1-\theta)\widetilde{P_t}^{1-\varepsilon}{}_t + \theta P_{t-1}^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} \tag{25}$$

This can be transformed into:

$$\Pi_t^{1-\varepsilon} = (1-\theta)X_t^{1-\varepsilon} + \theta \tag{26}$$

with Π_t denoting gross inflation rate at *t*, while $X_t \overset{\text{def}}{=} \widetilde{P}_t / P_{t-1}$. 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

$$\pi_t = \overline{\Pi}^{\varepsilon-1}(\overline{\Pi}^{1-\varepsilon} - \theta)^{\frac{-\varepsilon}{1-\varepsilon}}(1-\theta)^{\frac{1}{1-\varepsilon}} x_t \tag{27}$$

Note that under $\overline{\Pi} = 1$, expression (27) collapses to the standard formula $\pi_t = (1-\theta)x_t$. Now denote the parameter accompanying x_t in (27) as c for convenience of exposition. Expression (27) shall be used in the derivation of recursive definition of 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):

$$\Delta_t = \theta\Delta_{t-1} + \frac{1-\theta-c^2}{c^2}\pi_t^2 \tag{28}$$

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

$$\sum_{t=0}^{\infty}\beta^t\, var_n p_{n,t} = \frac{1}{1-\theta\beta}\frac{1-\theta-c^2}{c}\sum_{t=0}^{\infty}\beta^t\,\pi_t^2 \tag{29}$$

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

$$\mathcal{L}_t = \sum_{i=0}^{\infty}\beta^i\left[\pi_t^2 + \varepsilon^{-1}\frac{(1-\beta\theta)c^2}{1-\theta-c^2}(\sigma+\phi)y_t^2\right] \tag{30}$$

Equation (30) allows to calibrate 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 one-period-ahead expected inflation rate) and $\kappa = 0.024$ (i.e. the parameter for 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 (8). 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) 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 literature standards and, conditionally upon that, then set θ so as 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 production function and from a direct calibration based on 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 marginal effect on the reduced form parameters in (8), and hence on our results. The calibration of $\varepsilon = 3$ in the New Keynesian monopolistic competition model is typically set so as to imply a markup of 50%. Also, even large changes in ε (that we consider carrying 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 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 natural interest rate. We set $\rho = 0.8$ like 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 (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).

Finally, we calibrate the steady state natural interest rate at the level consistent with β, σ and the growth rate of potential output equal to 0.02/4. This 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 $\bar{\pi}$ and PLB at 2%, and the natural interest rate at 4.28%. As mentioned in the introduction, 2% matches inflation target most frequently seen in advanced economies, as well as the floor for policy rate of Bank of England since its foundation in 1694 until 2009 (and of most other central banks too).

(Table 1)

4. Results

As indicated in the introduction, four combinations of ZLB and PLB policies 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.

We scrutinize all four combinations, because one cannot prejudge which type of the policy, ZLB or PLB, is more likely to be credible. On the one hand, the ZLB policy signals dovish bias. By contrast PLB can be considered as a sign of hawkish bias, limiting the actual probability of the bank allowing inflation to exceed the target. On the other hand, the empirical evidence, albeit very scarce, suggests that the ZLB policy can undermine the trust in central bank (Albinowski at al., 2014).

We start the comparison of the ZLB and PLB policies as if the ZLB policy has no side (adverse) effects such as strengthened post-crisis financial frictions, delayed restructuring or heightened uncertainty. It is not a surprise that on 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.[10]

In the 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 the case (b), the difference is much less profound. Still the ZLB policy allows to 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 short lived than under the PLB policy. By contrast, in the 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 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 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 bank with capability to stabilize economy when the ZLB binds, we go a step further and argue that the credibility can deprive central bank of strong justification for aggressive interest rates cuts all the way to zero. Lastly, in the 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)

Next we relax the assumption of no side effects of the ZLB policy. We approximate them, instead. as larger inertia of shock to r_t under the ZLB policy, for reasons explained in the section two. We check how much less persistent a shock under the PLB policy would have to be, compared to one dealt with 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 the case (a) and (b), the difference in ρ required for the PLB policy to pay off is relatively small. Under the baseline calibration it amounts to 0.063 in the case (a) and 0.092 in the case (b). Hence, it is lower when central bank fails to commit (and welfare losses are large) than otherwise. 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.[11]

Only in the case (d), the required difference in ρ would have to be large for the PLB policy to outperform the ZLB policy in terms of welfare. This is the only case, when the break-even ρ under the PLB policy (0.425) is out of the range considered in the literature on the ZLB (see figure 6). This case highlights again the significance of central bank's credibility. Should interest rates cuts to zero condition it, central bank would not have to attach much weight to possible side effects of the ZLB policy.

(Figure 6)

Interestingly, the more persistent or the larger the shock, the lower the required difference in ρ (see table 2). This relationship casts doubt on aggressive interest rates cuts to zero in response to severe negative shock, which since Eggertsson and Woodford (2003) have been unanimously advocated by the whole strand of the literature on the ZLB envisaging

[10] 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.

[11] We do not describe the 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 at all.

‘fundamental’ shock. The results suggests, instead, that the more severe the shock, the more cautious the central bank’s response should be, and especially so when its credibility is dubious. Note that the reason for the suggested caution is not the need to preserve some powder dry for future emergencies, as some older papers argued. It is the risk of side effects of ZLB policy.

(Table 2)

We check for sensitivity of our results to assertion that certain costs related to fast restructuring could be avoided or reduced if restructuring was 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 so as 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). Respective ratio amounts to 6.0 in the case (a), 4.3 in the case (b), and 9.4 in the case (c) (see figure 7).[12]

(Figure 7)

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 potential output growth range under our consideration 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, then it should be avoided by countries of both fast and slow economic growth.

The value of $\bar{\pi}$ has a more significant, however 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. Hence, 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 elasticity of economies 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, except for the case (c), where the relationship is opposite albeit still very weak. Recall that in this case, PLB policy dominates the 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 still comfortably holds. 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 markups).[13] The required difference in ρ very feebly increases with rising ε (except for 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, it strengthens, if anything, the conclusions drawn under the baseline calibration. Namely, in the 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 the case (d) moderately high ε raises its value to the level from that range. Put it differently, even if the ZLB policy is pursued under commitment, fairly limited side effects of the ZLB policy ought to be enough for PLB policy to pay off in terms of welfare. This holds for any ε, if the

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

[13] Recall that λ depends on ε. We consider a wider range of ε than justified by results of empirical studies on markups, in order to cover values of λ that appears in the literature on the ZLB.

PLB policy is under commitment too, and for moderately high ε, if central banks fails 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. 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 rising θ. This is irrelevant in the case (b), where break-even ρ remains within the range considered in the literature on the topic for any value of θ. Nevertheless in the case (d), a bit larger θ than in the baseline calibration suffices to increase break-even ρ to the level from that range. All in all, 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, then more valid reasons for avoiding the ZLB policy are displayed by countries with more rigid labor supply and higher degree of nominal rigidities, albeit more fierce competition (manifested in lower markups).

(Table 3)

In summary, the findings provide support for establishing a PLB. Note that it would by no means rule out quantitative easing in order to keep possible panic down in systemically important segments of financial sector after the outburst of financial crisis. Such a 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).

5. Conclusions

If the ZLB policy has no 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, credibility of central bank is of crucial importance. If central bank failed to commit under the ZLB policy, while its commitment under the PLB policy was perceived credible, the latter policy would outperform the former in terms of welfare. In turn, under similar credibility of both policies, quite limited 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, which could be reduced or even avoided through slow restructuring. Moreover, the larger and the more persistent the shock, the weaker the side effects required for PLB policy dominance over ZLB policy. Only if the ZLB helped central bank to credibly commit, while the PLB policy undermined central bank's credibility, the required side effects would have to be large. Robustness check suggests that the findings hold for economies with both fast and slow potential output growth, with low and higher inflation target, flexible and more rigid. If anything, they are more robust for economies with slow potential output growth, low inflation target, strong rigidities: nominal and in labor supply, although tough competition.

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

This paper is the first step to accommodating both positive and side effects of the ZLB policy (or the extremely accommodative policy in general). However, further steps should follow in order to establish optimal central bank's response to severe shock. The paper suggests that the aggressive interest rates cuts all the way to zero may not be the right response. It might be that central bank should establish a PLB instead and use quantitative easing to keep panic down in systemically important segments of financial sector. Bagehot (1892) could be wright.

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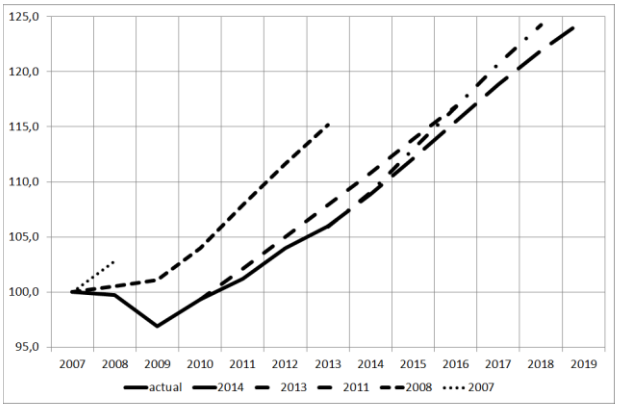
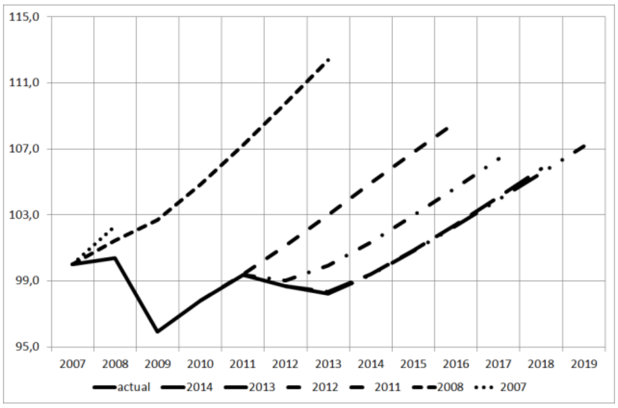
Figure 1. IMF GDP forecasts generated in the years 2007-2014 and actual GDP growth path (2007-2013)

a: United States



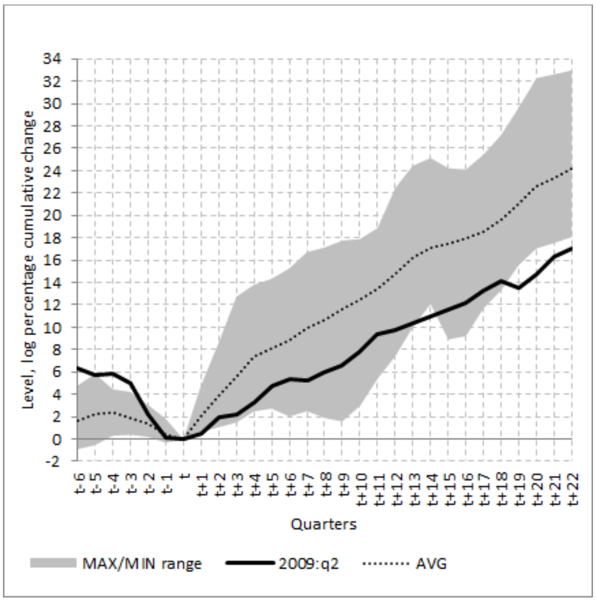
b: Euro area



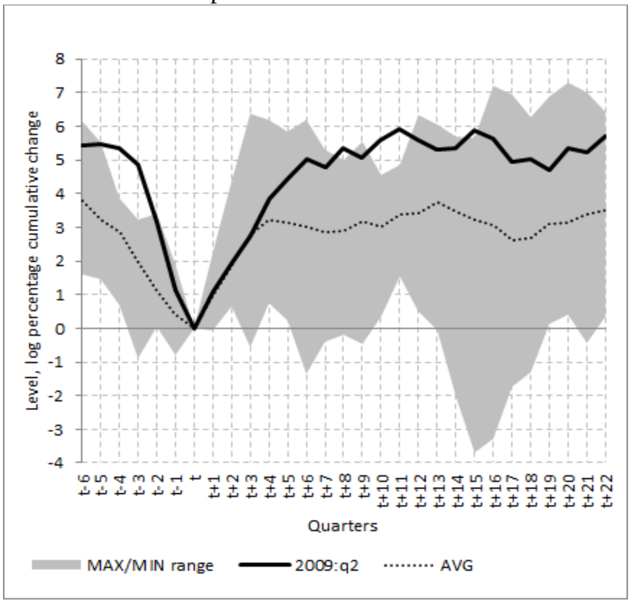
Source: IMF WEO database, April 2007, 2008, 2011, 2013 and 2014. *Note:* This figure represents actual (solid line) and forecasted (dotted lines) GDP growth paths in the United States (a) and Euro area (b). It shows that actual GDP dynamics was turned out to be poorer than expected. 2009, 2010 and 2012 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 after previous recoveries since the second world war

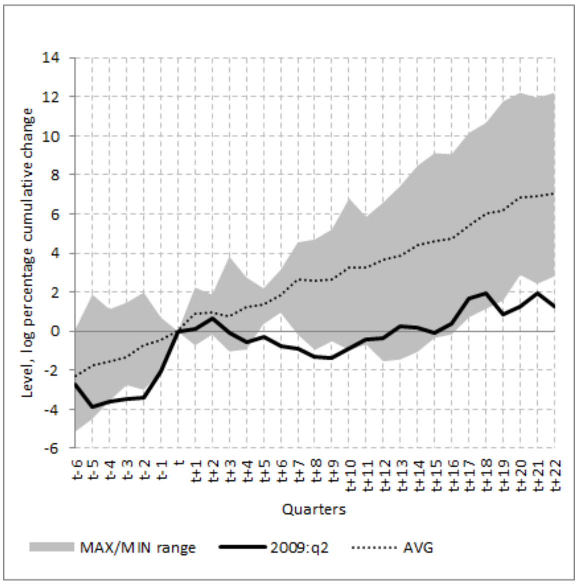
a: GDP



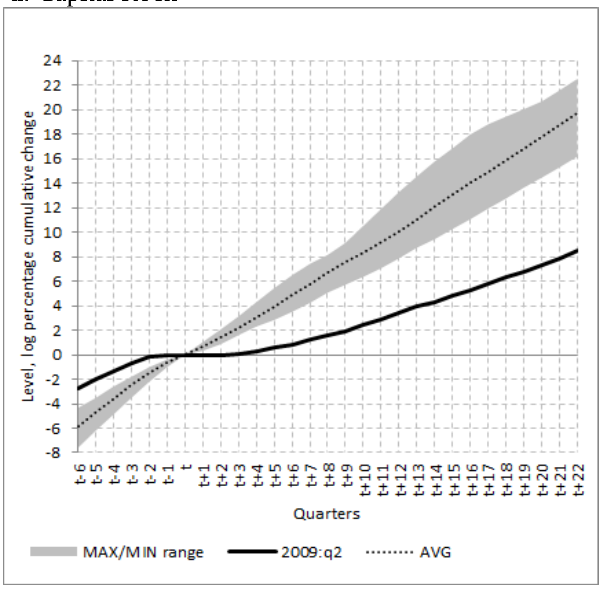
b: Utilization of capital and labour



c: TFP

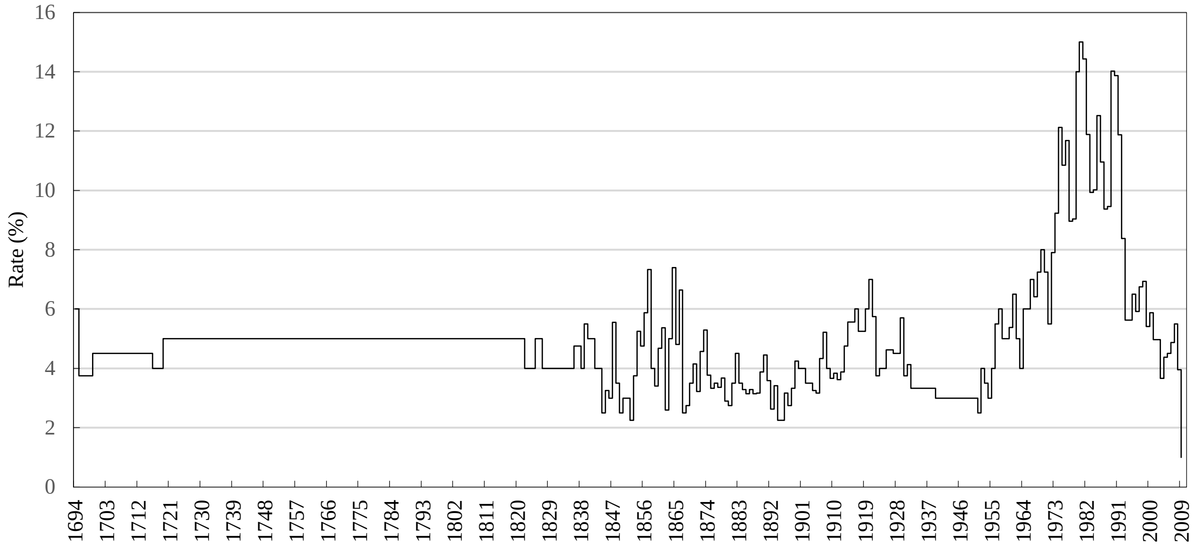


d: Capital stock



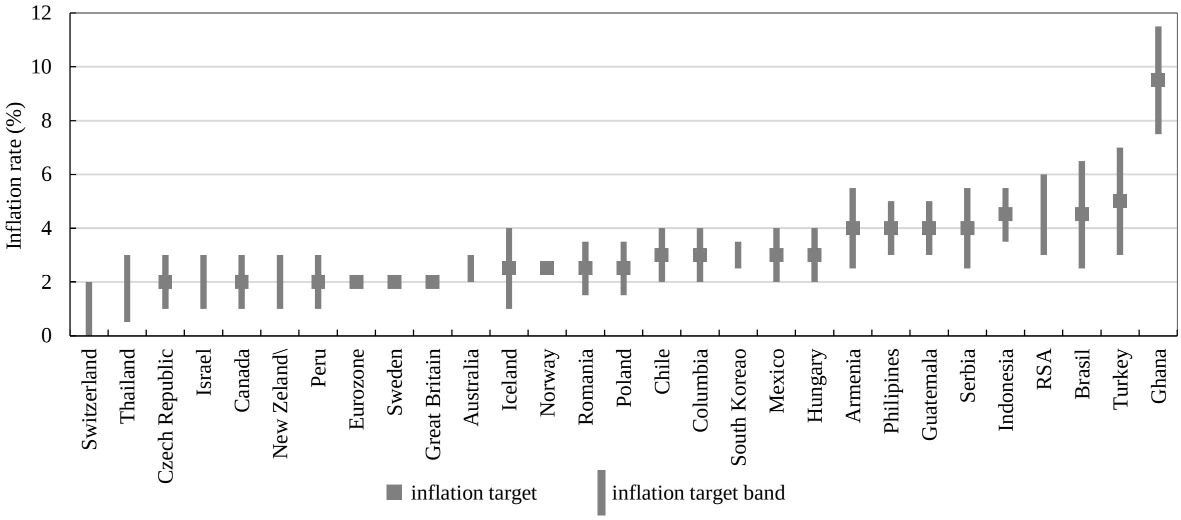
Source: NBP, Economic Institute, based on Fernald (2014). *Note:* This figure reports cumulative change of GDP and its main components in the United States after the Great Recession and previous recoveries since the second world war. End of 10 recessions considered is dated in accordance with the NBER. 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



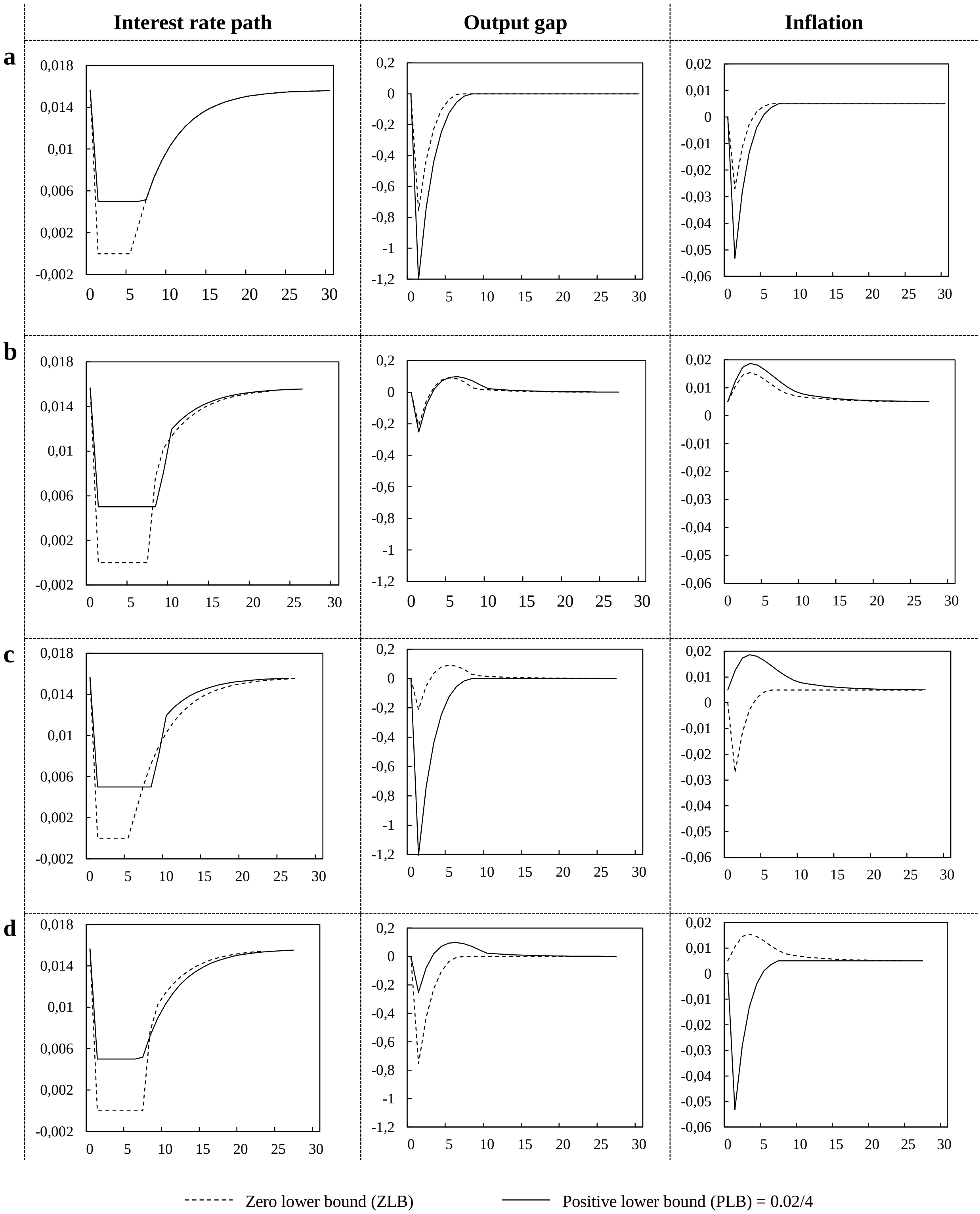
Source: Bank of England. *Note:* This figure reports the base rate of the Bank of England during the period 1694-2009. Data refer to bank rate (for 1694-1972), minimum lending rate (for 1972-1981), minmum band 1 dealing rate (for 1981-1996), repo rate (for 1997-2005) and official bank rate (for 2006-2009). 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



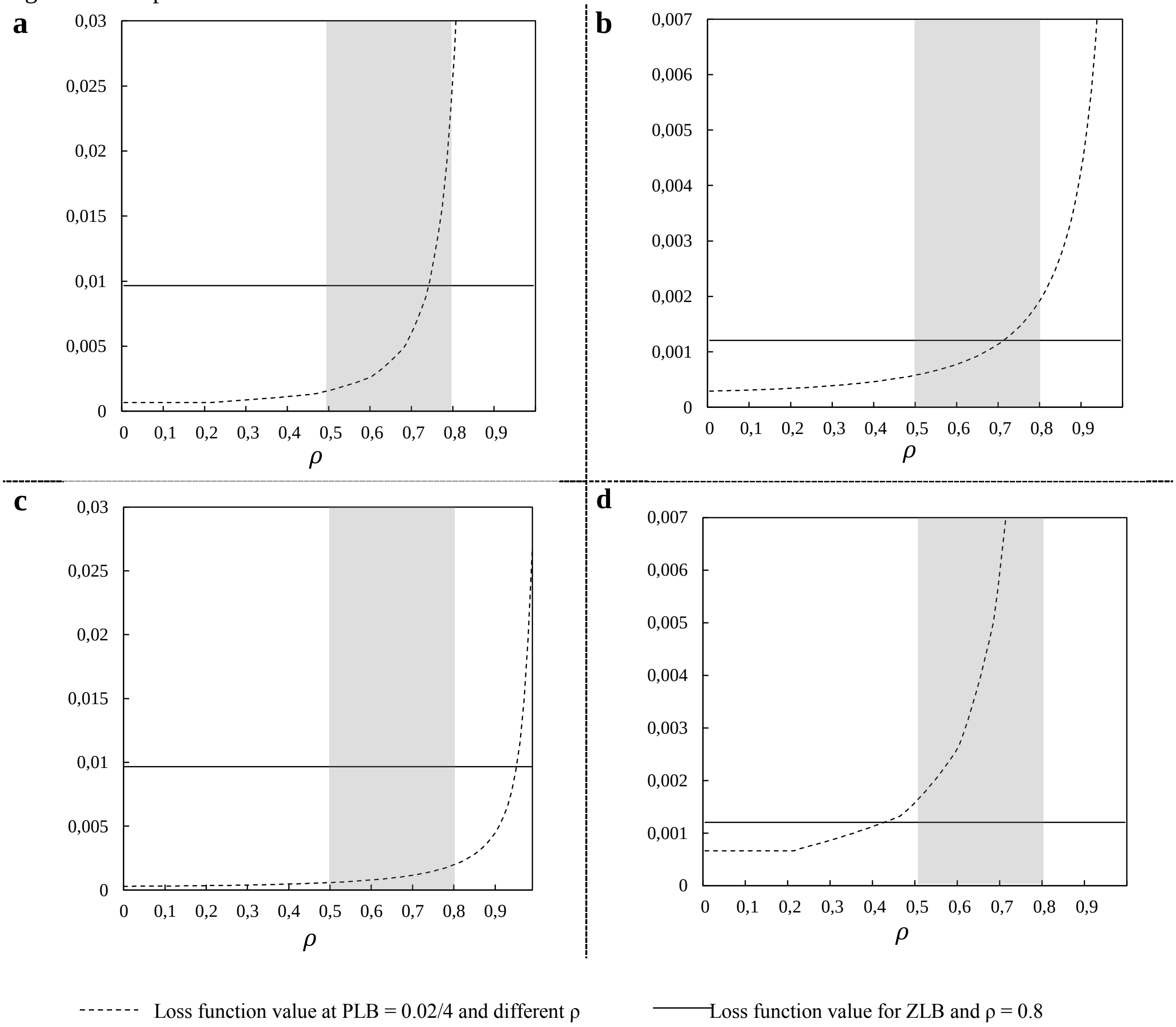
Source: NBP Economic Institute (based on respective central banks' web pages). *Note:* This figure depicts inflation targets of central banks which have introduced direct inflation targeting as monetary policy strategy. It shows that 2% is the level matching inflation targets most frequently seen in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

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



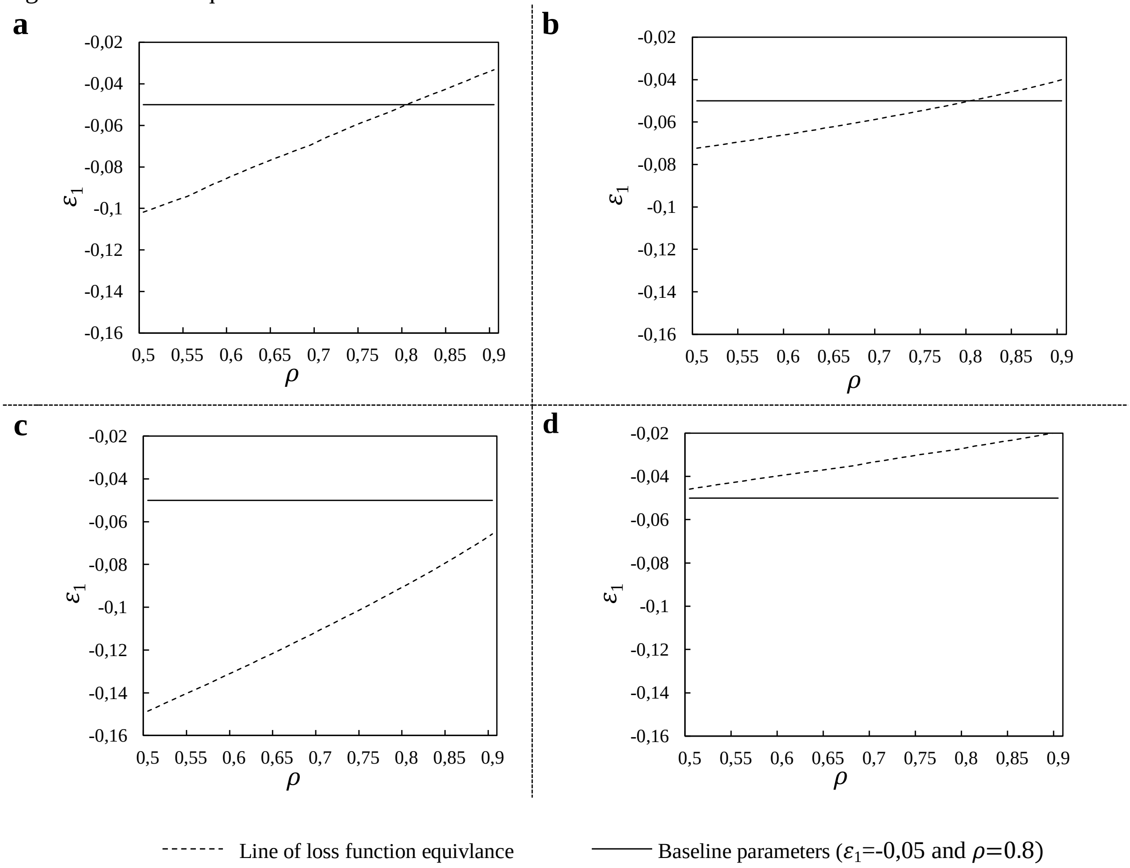
Source: Authors. *Note:* This figure compares the model's results for interest rate, output gap and inflation.The vertical axis represents the steady state value of respective variable for t=0 and then their deviation from the steady state. The horizontal axis depicts the qarters. Four combinations of 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. 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 7. 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.

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)
λ	$0.048/(4^2)$	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)
$y^P_{t+1}-y^P_t$	$0.02/4$	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	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9
Break-even ρ	(a) ZLB and PLB under discretion	0.324	0.377	0.475	0.533	0.605	0.667	0.737	0.803	0.868
	(b) ZLB and PLB under commitment	0.257	0.339	0.416	0.493	0.565	0.637	0.708	0.779	0.85
	(c) ZLB under discretion and PLB under commitment	0.649	0.684	0.744	0.797	0.851	0.902	0.952	0.994	
	(d) ZLB under commitment and PLB under discretion					0.22	0.308	0.421	0.512	0.605

Panel **B**	ϵ_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	0.711	0.737	0.749	0.757	0.762	0.766	0.769
	(b) ZLB and PLB under commitment		0.549	0.668	0.708	0.729	0.742	0.751	0.757	0.762
	(c) ZLB under discretion and PLB under commitment		0.8	0.843	0.92	0.952	0.969	0.982	0.992	0.999
	(d) ZLB under commitment and PLB under discretion			0.347	0.421	0.445	0.449	0.453	0.456	0.459

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). 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 variuos 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**	$y_{t+1}^P - y_t^P$ (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**	$\bar{\pi}$ (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**	φ (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**	ε (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**	θ (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). Respective panels show break-even ρ calculated for variuos potential GDP growth rates ($y_{t+1}^P - y_t^P$, 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.