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Is Poland at risk of the zero lower bound?

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Abstract

In early 2015, the policy (*open market operations*) rate of Narodowy Bank Polski was reduced to an all--time low of 1.5%. At the same time, prices of consumer goods and services dropped by 1.5% in year-on--year terms. This raised concerns that Poland might become the next country to hit the zero lower bound (ZLB) constraint on nominal interest rates. The purpose of this paper is to examine the scale of this risk and its possible consequences. According to our results, the odds of the Polish economy hitting the ZLB remain low, despite having risen considerably in 2014–2015. At the same time, the consequences of such a scenario would be substantial as the ZLB would amplify the economy's responses to adverse demand shocks and make their impact more persistent. The current level of the inflation target (2.5%) protects the Polish economy against the zero lower bound to a signifficant degree. However, its potential reduction would significantly increase the likelihood that this threat materializes.

Keywords: zero lower bound, Polish monetary policy, small open economy

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1. Introduction

Both the literature (discussed in more detail in the following section) and the empirical data from countries which have faced the zero lower bound (ZLB) constraint on nominal interest rates in the recent years show that it may have serious consequences for macroeconomic stability. The ZLB reduces the central bank's capacity to stabilize macroeconomic conditions, thus boosting inflation and output volatility. In early 2015, the policy rate of Narodowy Bank Polski was reduced to its all-time low of 1.5%. At the same time, the prices of consumer goods and services sank by 1.5% in year-on-year terms. As a result, concerns arose that the Polish economy might be the next in line to hit the ZLB.

In this paper we examine the ZLB phenomenon in the context of the Polish economy. In particular, our aim is to assess the probability of Poland hitting the ZLB, possible consequences of such a scenario, and its relationship with the level of the inflation target. To this end, we use a dynamic stochastic general equilibrium (DSGE) model of a small open economy, estimated with Bayesian methods on data for Poland and the euro area.

The main findings of our study are as follows. First, the probability of Poland hitting the ZLB is relatively low. However, while it was virtually zero until 2013, it has begun to rise sharply more recently. Still, even when deflationary processes were at their most severe at the turn of 2014 and 2015, the probability of the ZLB scenario unfolding in Poland in a 3-year horizon did not exceed 6%. Second, the current inflation target is high enough to provide good insurance against the ZLB as the estimated median time to hit the ZLB, starting from the steady state, is over 100 years. However, a reduction of the target would significantly increase the risk of hitting the zero lower bound. For example, if the target was 1.5%, the economy would reach the ZLB after an average of only 22 years, with a 25% probability of this risk materializing in less than seven years. Third, the impulse response analysis shows that the economy confronted with the zero lower bound reacts more weakly to positive supply shocks and more strongly to negative disturbances to consumption preferences, government expenditure, risk premia or external shocks. Fourth, in line with findings from the previous literature, the effectiveness of fiscal stimulus increases significantly under the ZLB: the government expenditure multiplier may be even twice as high as in normal times. Fifth, the spill--over of a crisis in the euro area to Poland is, *ceteris paribus*, smaller if the euro area is stuck at the ZLB.

The rest of the paper is divided into 5 sections. In Section 2, we discuss briefly the ZLB problem. Sections 3 and 4 present the model and its estimation. In Section 5, we discuss the results of our simulations. Section 6 concludes.

2. The zero lower bound

The zero lower bound is said to be binding when the central bank has reduced the policy rate to near zero, whereas the current and anticipated macroeconomic situation call for further cuts. In this section we discuss briefly two key issues related to the ZLB: the ways to avoid it and the consequences of being trapped. Both are closely related to our simulations presented in the next sections. For the sake of brevity we do not discuss unconventional monetary policy instruments that can be used at the ZLB. Interested readers can see, among others: D'Amico and King (2010), Greenwood and Vayanos (2008),

Krishnamurthy and Vissing-Jorgensen (2011), Joyce et al. (2011), Gagnon et al. (2011), Hamilton and Wu (2012), Gambacorta, Hofmann and Peersman (2012), Engen, Laubach and Reifschneider (2015), Chen et al. (2015) or Woodford (2012).

2.1. Avoiding the ZLB

A key question related to the ZLB is, obviously, how to avoid it. The literature has proposed a number of methods to reduce the risk of hitting the ZLB. Below we concentrate on three that are closely related to the conduct of monetary policy: changing the inflation target, modifying the monetary policy strategy and changing the degree of aggressiveness of monetary policy reactions. The vast literature on directly relaxing the constraints generated by the existence of cash is not discussed here. See e.g. Buiter and Panigirtzoglou (2003), Buiter (2009), Mankiw (2009) or Ilgmann and Menner (2011). For more details on this issue, see also Adam and Billi (2006, 2007), Nakov (2008) or Svensson (2003).

The first way to insure against the ZLB is to change the inflation target. As argued by Blanchard, Dell'Ariccia and Mauro (2010), raising it should lead to lower probability of the ZLB. This happens because a higher target means (over a longer horizon, once the adjustment processes have been completed) permanently higher inflation expectations. For a given natural interest rate (expressed in real terms, which we assume not to depend directly on monetary policy), higher inflation expectations raise the nominal equilibrium rate. Hence, a higher inflation target implies higher nominal interest rates and a larger buffer, allowing for deeper cuts in the nominal interest rate when adverse shocks hit. The problem with the above solution is that higher inflation also involves welfare losses for the economy. The literature provides a long list of reasons why inflation is harmful – the shoe-leather cost, the information cost, the cost of non-optimal allocation of resources or the inflation tax. With this in mind, Coibion, Gorodnichenko and Wieland (2012) formally investigated whether central banks should increase inflation targets in the context of the ZLB. The paper weights a potentially large, yet incidental cost of the ZLB against a relatively small but more permanent cost of higher average inflation. Using a New Keynesian model calibrated for the United States, the authors conclude that the optimal rate of inflation is positive, but not exceeding 2%. This suggests that the current inflation targets of central banks already take into account the lower bound on nominal interest rates. It is also worth noting that no central bank has yet decided to increase the inflation target because of the ZLB risk.

The second idea is to change the monetary policy strategy (Billi 2013; Nakov 2008). According to the inflation targeting (IT) strategy, in times of low (high) inflation the central bank promises to raise (reduce) inflation to the target. Price level targeting (PLT) is an interesting alternative to IT. Under PLT, the central bank conducts its monetary policy with a view to keeping price level growth close to an *ex ante* designated path. As a result, following a period of low inflation, it is necessary to temporarily generate inflation above the trend. This element of the strategy is crucial in the ZLB context. When inflation falls, future inflation expectations rise. This implies a drop in long-term real interest rates, which in turn leads to an expansion in aggregate demand, thus reducing the decline in inflation. As a result, the *ex ante* probability of hitting the lower bound decreases.

The third way to prevent the ZLB is to increase the aggressiveness of monetary policy. As shown by Adam and Billi (2006, 2007) and Nakov (2008), optimal monetary policy takes a particular form in

the ZLB environment. When the probability of hitting the ZLB rises, the central bank should reduce the interest rates sharply, and in particular more aggressively than it would have done in normal times. In this way the bank generates a temporary (in contrast to permanent, stemming, e.g. from raising the target) rise in inflation expectations, and hence a decrease in real interest rates, which in turn increases the probability of avoiding the ZLB.

2.2. Consequences of hitting the ZLB

The second issue related to the ZLB that we briefly discuss are its possible adverse consequences. Below, we concentrate on two that have received most attention in the literature: the inability to use conventional (i.e. interest rate-based) monetary policy by the central bank and the modified macroeconomic dynamics at the ZLB.

The first problem resulting from the ZLB is that it limits the ability of the central bank to stimulate the economy. The reason is obvious – the central bank, which cannot lower the policy rate below zero, looses its key instrument, which negatively affects macroeconomic stability. Since the outbreak of the financial crisis, when the ZLB started to spread to a number of economies, this issue has been discussed by both theoretical and empirical literature. For example, Ireland (2011) estimated in a New Keynesian framework that, had it not been for the zero bound for interest rates, the 2009 recession in the United States would have been less severe by approximately 1 percentage point. Gust, Lopez-Salido and Smith (2012) estimated a nonlinear DSGE model for the United States and showed that the US GDP was lower by 1% on average over 2009–2011 because the interest rates could not be sufficiently reduced.

The second problem with the ZLB is linked to the change in the economy's reactions to shocks. When interest rates are at the ZLB, the response to negative (ie. output-reducing) disturbances may become more pronounced, while the response to some positive shocks may be weaker. For instance, Neri and Notarpietro (2014) showed that a positive technological disturbance, which normally leads to an increase in GDP, may result even in a GDP decline at the ZLB. Baürle and Kaufmann (2014) showed that risk premium shocks are significantly amplified at the ZLB. This case is of particular importance for Switzerland, where the inflow of financial capital caused an enormous appreciation pressure, pushing the economy deeper into the trap. Brzoza-Brzezina (2016) showed that amplification of shocks at the ZLB depends to a large extent on the economy's openness: the consequences of the ZLB are more severe in a closed economy than in a small open economy. Other studies (e.g. Bodenstein, Erceg, Guerrieri 2009; Haberis, Lipinska 2012) showed that international spillovers are stronger when the ZLB binds.

3. The model

To conduct an empirical analysis focused on the Polish economy, we consider a fairly standard DSGE model of a small open economy, founded on the seminal work of Obstfeld and Rogoff (1995) and its later development by Gali and Monacelli (2005). Compared to more recent applications, our model's structure is slightly richer than that of Justiniano and Preston (2010) and somewhat simplified in comparison with Adolfson et al. (2007) or Christoffel, Coenen and Warne (2008a). The model economy

is populated by households, producers of intermediate and final goods, importers, as well as fiscal and monetary authorities. The rest of the world is treated exogenously and represented by a simple vector autoregressive (VAR) process.

In what follows we present the problems of agents. The Appendix presents a complete list of log-linearised equations that we use to estimate and simulate the model.

3.1. Households

There is a continuum of households indexed by *j*. A typical household is assumed to maximize the objective function:

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\varepsilon_{g,t} \frac{\left(c_{j,t} - \xi c_{t-1}\right)^{1-\sigma}}{1-\sigma} - \varepsilon_{l,t} \frac{l_{j,t}^{1+\varphi}}{1+\varphi} \right] \tag{1}$$

where c_t denotes consumption and l_t stands for hours worked. The parameters σ and φ are the inverse of the elasticities of, respectively, intertemporal substitution and labour supply, whereas ξ describes the degree of external habit formation in consumption. Households' preferences are disturbed by consumption preferences shocks $\varepsilon_{g,t}$ and labour supply shocks $\varepsilon_{l,t}$.

Households also own capital k_t and adjust its supply through investment x_t. The capital law of motion is:

$$k_{j,t+1} = (1-\delta) k_{j,t} + Y_t \left(1 - S\left(\frac{x_{j,t}}{x_{j,t-1}} \right) \right) x_{j,t} \tag{2}$$

where $S(\cdot)$ is a function which describes the investment adjustment cost and whose second derivative in the steady state is S'', while Y_t is a stationary technological investment-specific shock.

Each household *j* provides diversified work services $l_{j,t}$. The total labour supply is specified by the following Dixit-Stiglitz aggregator:

$$l_t = \left[\int_0^1 \left(l_{j,t} \right)^{\frac{1}{\lambda_w}} dj \right]^{\lambda_w} \tag{3}$$

where λ_w is the wage markup.

In each period each household can reoptimize its wages with probability $1-\theta_w$. Wages of the remaining households are indexed according to:

$$W_{j,t+1} = \pi_t^{\delta_w} \bar{\pi}^{1-\delta_w} W_{j,t} \tag{4}$$

where $\bar{\pi}$ is the inflation target, $\pi_t \equiv P_t / P_{t-1}$ is inflation, P_t is the price level, while δ_w is a parameter that determines to what extent wages are indexed to past inflation.

All assets held by households are one-period. We also assume that households have access to a complete insurance market that allows them to insure against idiosyncratic wage risk. As a result, income of all households is the same despite wage stickiness. Households' budget constraint can be written as follows:

$$P_t c_t + P_t x_t + D_t + e_t B_t + T_t = D_{t-1}\left(1+i_{t-1}\right) + e_t B_{t-1}\left(1+i^*_{t-1}\right)\Phi\left(a_{t-1,}\phi_t\right) + R_t k_t + W_{j,t} l_{j,t} + \Xi_{j,t} \tag{5}$$

where D_t are claims on other domestic households, B_t are claims on foreign households, e_t denotes the exchange rate, R_t is the rental rate on capital, i_t and i^*_{t-1} are one-period interest rates, respectively at home and abroad, T_t denotes lump-sum taxes, and Ξ_t stands for net payments from labour income insurance. Function $\Phi(\cdot)$ describes the risk premium associated with foreign transactions and is specified as follows:

$$\Phi\left(a_{t-1,}\phi_t\right) = \exp\left[-\chi\left(a_{t-1} + \phi_t\right)\right] \tag{6}$$

where:

$$a_t \equiv \frac{e_t B_t}{\bar{y} P_t} \tag{7}$$

is the ratio of net foreign assets to steady-state output $\bar{y}$, ϕ_t, denotes a risk premium shock, while χ is the risk premium elasticity with respect to foreign debt.

3.2. Firms

Producers of final goods. Final goods $\tilde{y}_t$, used ultimately in the home country for consumption, investment and government purposes, are manufactured by producers of final goods in accordance with the following formula:

$$\tilde{y}_t = \left[\left(1-\omega\right)^{\frac{1}{\eta}} y_{H,t}^{\frac{\eta-1}{\eta}} + \omega^{\frac{1}{\eta}} y_{F,t}^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{1-\eta}} \tag{8}$$

where $y_{H,t}$ and $y_{F,t}$ are Dixit-Stiglitz aggregators of local and foreign intermediate goods:

$$y_{X,t} = \left[\int_0^1 y_{X,i,t}^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{\varepsilon}{\varepsilon-1}}, \quad X \in \left\{H, F\right\} \tag{9}$$

while ω is the share of foreign goods in the basket of goods consumed in the home country.[1] The elasticity of substitution between domestic and foreign goods is defined by parameter η, while the elasticity of substitution between intermediate goods is ε.

[1] The model does not take account of the option of re-exporting imported goods. We consider this fact while calibrating the ω parameter.

Export goods are produced analogously:

$$y^*_{H,t} = \left[\int_0^1 y^*_{H,i,t}^{\frac{\varepsilon-1}{\varepsilon}} di \right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{10}$$

Producers of domestic intermediate goods. In the model we have a continuum of domestic firms producing intermediate goods. They are owned by households and operate under monopolistic competition. Every good *i* is produced in line with the following production function:

$$y_{H,i,t} = z_t k_{i,t}^{\alpha} l_{i,t}^{1-\alpha} \tag{11}$$

where z_t is a productivity shock.

It is assumed that price-setting in this sector is defined by the Calvo mechanism and prices are denominated in the currency of the producer so that $P_{H,i,t} = P^*_{H,i,t} e_t$. With probability $1 - \theta_h$ firm *i* maximizes

$$\mathrm{E}_0 \sum_t^{\infty} \theta_h^t \Lambda_t \left(P_{H,i,t} - MC_t \right) \left(y_{H,i,t} + y^*_{H,i,t} \right) \tag{12}$$

subject to the constraint implied by aggregation problems (9) and (10) and marginal cost MC_t consistent with production function (11), where Λ_t is the Lagrange multiplier on the household's budget constraint (5).

Firms that do not optimize their prices change them according to:

$$P_{H,i,t+1} = \pi_{H,t}^{\delta_h} \, \bar{\pi}^{1-\delta_h} P_{H,i,t} \tag{13}$$

where δ_h measures the extent to which the price is indexed to inflation $\pi_{H,t} = P_{H,t} / P_{H,t-1}$.

Importers. A continuum of importers are also owned by households and operate under monopolistic competition. Importers purchase intermediate goods from abroad at price P_t^*, and then differentiate and sell them at a price determined in accordance with the Calvo scheme. Hence, a fraction $1 - \theta_f$ of optimizing importers maximize

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \theta_f^t \Lambda_t \left(P_{F,i,t} - e_t P_t^* \right) y_{F,i,t} \tag{14}$$

subject to the constraint consistent with aggregation problem (9).

The prices set by remaining firms follow

$$P_{F,i,t+1} = \pi_{F,t}^{\delta_f} \, \bar{\pi}^{1-\delta_f} P_{F,i,t} \tag{15}$$

where δ_f measures the extent to which prices are indexed to inflation $\pi_{F,t} = P_{F,t} / P_{F,t-1}$.

Monetary and fiscal policy

The monetary authority follows a Taylor-like rule that can be written in a log-linearised form that also takes into account the zero lower bound on the nominal interest rates (which corresponds to the inability to reduce $\hat{\imath}_t$ by more than $\bar{\imath}$ – the steady-state value of $\imath_t$):

$$\hat{\imath}_t = \max\left\{-\bar{\imath};\ \psi_i \hat{\imath}_{t-1} + (1-\psi_i)\left[\psi_y \hat{y}_t + \psi_p \hat{\pi}_t + \psi_{dp}\left(\hat{\pi}_t - \hat{\pi}_{t-1}\right)\right] + \sigma_m \varepsilon_{m,t}\right\} \tag{16}$$

where $\varepsilon_{m,t}$ is a monetary shock, variables with hats denote log-deviations from the steady states and y_t is total domestic production:

$$y_t = y_{H,t} + y^*_{H,t} \tag{17}$$

Government expenditure g_t is treated as exogenous and financed from lump-sum taxes T_t imposed on households. Due to the Ricardian equivalence holding in the model, it does not matter whether the government issues debt.

Foreign economy

The foreign economy is characterised by a 3-equation VAR model with two lags, describing foreign GDP y_t^*, foreign inflation $\pi^* \equiv P_t^*/P_{t-1}^*$, and the foreign interest rate i_t^*.

Demand for exports is determined by similar factors as those affecting choices made by the home country (see equation (8)), i.e. it depends on the level of economic activity abroad and the price competitiveness of domestic production:

$$y^*_{H,t} = \nu \left(\frac{P_{H,t}}{e_t P_t^*}\right)^{-\eta} y_t^* \tag{18}$$

where v is a constant which describes foreign preferences.

Market clearing

The model is closed with a standard set of market clearing conditions. In particular, the following identity must be satisfied

$$\tilde{y}_t = c_t + x_t + g_t \tag{19}$$

Stochastic shocks

Except for the monetary shock $\tilde{\varepsilon}_m$, which is white noise, and foreign variables, that are jointly determined in a VAR model, all disturbances are assumed to evolve according to an AR (1) process of the log-linearized form:

$$\hat{x}_t = \rho_x \hat{x}_{t-1} + \sigma_x \hat{\varepsilon}_{x,t} \tag{20}$$

where $\hat{\varepsilon}_{x,t} \sim N(0,1)$, ρ_x, is an autocorrelation parameter, and σ_x is the standard deviation of innovations.

Equilibrium

The log-linearized version of the model presented in the Appendix consists of 18 equations that, for a given sequence of 10 stochastic shocks $\varepsilon_{g,t}$, $\varepsilon_{l,t}$, γ_t, ϕ_t, z_t, g_t, $\varepsilon_{m,t}$, y_t^*, π_t^* and jointly determine the first-order accurate evolution of the following 18 endogenous variables: y_t, $\widetilde{y}_t$, c_t, x_t, l_t, k_t, r_t, w_t, $p_{k,t}$, π_t, $\pi_{H,t}$, $\pi_{F,t}$, λ_t, ι_t, mc_t, s_t, q_t, a_t.

4. Estimation

4.1. Calibration of parameters

Most of the model parameters were estimated using Bayesian methods. The remaining ones, which are either difficult to identify, or for which there is a firmly established consensus in the literature, were calibrated. We also made sure that we match the key steady-state proportions.

The share of government spending in GDP was set to 0.185, corresponding to the average share in the period 2000–2014. Parameter β was calibrated at a standard level of 0.99, the depreciation rate of capital δ at 2% per quarter (approx. 8% per annum), while the share of capital α was set to 0.3. The openness of the Polish economy was set to 0.28, in line with the share of Polish imports in GDP in our sample, after adjustment for import content of exports using the estimates of Bussiere et al. (2013). The calibrated parameters are shown in Table 1.

An important element of calibration is setting the average distance of the nominal interest rate from the lower bound. In the model presented in the previous section, this distance corresponds to the difference between the interest rate in the steady state (which is $\bar{\pi}/\beta - 1$), and the lower bound for interest rates (which is usually assumed to be zero). Determining the distances at such a level, however, generates two difficulties which may result in an underestimation of the probability of hitting the ZLB.

First, the practical experience with the ZLB has shown that the lower bound may bind money market interest rates at a level slightly higher than zero. More specifically, the euro area reached the lower bound already in 2012 Q4; nonetheless for the interbank market rate this meant a level of approx. 20 basis points (average over the period from 2012 Q4 to 2014 Q4, with very small variations). This lower limit for the euro area interest rate (EURIBOR 3M) rate was assumed in the simulations presented below. Since Poland has had no experience of being at the ZLB, the lower bound for the Polish interest rate (WIBOR 3M) was set at the same level.

Second, the steady-state level of the nominal rate implied by the discount factor and the inflation target is approx. 6.5% (in annualised terms), much above the sample average of this variable for Poland (5%) and the euro area (2%). Therefore, we decided to adjust the measurement equations linking WIBOR3M and EURIBOR3M with their model counterparts so that the equilibrium nominal rate equals the data average over the estimation sample. As a result of these adjustments, the distance of the steady-state nominal interest rate from its lower bound equals 4.8 percentage points for Poland and 1.8 percentage points for the euro area.

4.2. Data and estimation of parameters

To estimate the model we used ten macroeconomic variables – seven for Poland and three for the euro area. The data covered the period from 2002 Q1 to 2014 Q4. The following data were used for Poland: GDP (growth rate), consumption (growth rate), gross fixed capital formation (growth rate), HICP inflation, interest rate in the interbank market (WIBOR 3M), real wages (growth rate) and the real effective exchange rate (REER). A detailed description of the dataset used for estimation can be found in the Appendix. As regards the foreign economy, we followed Justiniano and Preston (2010) and estimated a three-equation VAR(2) model with the Minnesota prior (Litterman 1979), where the prior mean on first own lags was set to 0.75, while that for the remaining parameters was set to 0. The VAR model included the euro area interest rate (EURIBOR 3M), HICP inflation and GDP (deviation from HP trend).

As regards estimated structural parameters, their prior assumptions were taken from the literature. In particular, for consumption habits ξ and elasticity of substitution η between domestic production and imports, we followed Christoffel, Coenen and Warne (2008b). As for the Calvo parameters, indexation and monetary policy, the prior assumptions were taken from Grabek, Kłos and Koloch (2011). The prior for autocorrelation of all AR(1) shocks was centered at 0.75 with standard deviation 0.1 and that for their volatility was centered at 0.01 with infinite variance. As it is standard in the literature, the prior mean of the monetary shock volatility was assumed to be ten times smaller.

As Table 2 shows, for most parameters the posterior distributions do not differ significantly from those discussed in the literature that uses estimated DSGE models for the Polish economy of a similar structure (Kolasa 2009; Grabek, Kłos, Koloch 2011; Gradzewicz, Makarski 2013). In particular, the Calvo parameters imply the average duration of prices on the domestic market of approximately 2.5 quarters, while for prices of imported goods – slightly over 5 quarters. Price indexation parameters of around 0.5 indicate a significant (albeit consistent with the literature) persistence of inflation processes. The estimated Calvo parameter for wages indicates the degree of wage rigidity that is slightly smaller than that found for the euro area. Finally, the Taylor rule parameters indicate that the Polish central bank has actively counteracted inflation deviations from the target, but also cared about output stability.[2]

4.3. Forecasting properties of the model

To assess the probability of the Polish economy hitting the ZLB, we will use stochastic simulations.[3] For the results obtained from this experiment to be reliable, it is important that our model adequately describes the direction of change and uncertainty related to future levels of the interest rate.

To check if this is the case, we draw on the forecasting literature and apply the PIT (probability integral transformations) concept for forecasts generated from our model at different dates (cf. e.g. Diebold, Gunther, Tay 1998). For each period t in our sample we generate 10,000 stochastic simulations h periods ahead, taking the model parameter values fixed at their posterior means obtained for the whole sample, and randomly drawing from the relevant distributions of shocks. The thus obtained

[2] Detailed estimation results are available upon request.

[3] All simulations were performed with the Occbin package (Guerrieri and Iacoviello, 2015 that allows for solving DSGE models with occasionally binding constraints using piecewise linear approximation).

trajectories for the model variables approximate the distributions of their forecasts, i.e. predictive distributions. In other words, they describe the uncertainty of future realizations of these variables for the period $t + h$ evaluated at time t. Next, we count how frequently the actual values of the interest rate in our sample fall into the particular deciles of thus defined predictive distributions for different time horizons h. If the model correctly captures the uncertainty related to future evolution of this variable, the probability of a given realization to fall into each of the deciles should be 0.1.

Figure 1 illustrates the actual frequencies. While interpreting the graphs, one should bear in mind that we can use $T - h - 1$ number of interest rate realizations to determine these frequencies, where $T = 52$ denotes the length of the sample used in the estimation. Accordingly, the PIT graphs presented in the figure are based on a relatively small number of hits, especially for the 3-year horizon, so it is difficult to expect an ideal match.

Leaving aside these reservations, it can be seen that our model overestimates the probability of the interest rates attaining relatively high values. Also, a disproportionately high number of hits is reported for the middle deciles. Hence, the model seems to overestimate the scale of uncertainty related to future levels of the interest rate. However, most importantly from the point of view of the objectives of this work, the first decile of the model-implied predictive distributions for two and three--year horizons shows an almost ideal calibration. Hence, our method of assessing the probability of the Polish economy hitting the ZLB (i.e. an event from the left tail of the interest rate distribution) seems to be justified.

5. Results

In this section we will use the macroeconomic model previously described to evaluate the risk of the ZLB in Poland. This section serves two main purposes. First, we will discuss how the probability of Poland hitting the ZLB evolved in the period under examination. Second, we will show how the basic transmission of macroeconomic shocks would change if the Polish economy experienced the ZLB, as well as how effective fiscal stimulus – defined as an increase in the public sector expenses – could be under such conditions. Finally, we check how the ZLB in the euro area affects Poland.

5.1. The probability of hitting the ZLB

The risk of facing the ZLB is not constant over time and depends on the phase of the cycle and the current level of the interest rate. When macroeconomic conditions are weak, and consequently the interest rates are low, the probability of experiencing the ZLB is relatively high. Just a relatively small additional adverse shock might be sufficient for the zero bound on interest rates to restrict the central bank's capability to stimulate the economy.

In order to assess the likelihood of such an event, we generate for each quarter of our sample 10,000 stochastic simulations extending 3 years ahead. Shocks are drawn randomly from their estimated distributions. The parameter values for the standard deviations of shocks and their cross correlation (in the case of external shocks), as well as the values of all estimated structural parameters were set at their posterior means. Thus, the uncertainty built into our stochastic simulations results solely from the

randomness of shocks hitting the economy, and not from the uncertainty about the estimated model parameters. Next, we examine what percentage of the generated trajectories push the Polish economy into the ZLB in the horizon of 1, 2 or 3 years.

As suggested by Figure 2, until the beginning of 2012, the risk of the Polish economy hitting the ZLB was very low, not exceeding 1% in a three-year horizon, and virtually equal to zero in a one-year perspective. This changed significantly in early 2013, when the probability of the interest rates hitting the lower bound increased to 1% in the perspective of one year, and to more than 2% in a horizon three times longer. Another spike was observed in the last quarter of 2014, when the odds of hitting the ZLB within 3 years could be assessed at over 4%. While even this degree of risk can hardly be assessed as very high, its sudden increase cannot be ignored.

5.2. The role of the inflation target

One of the proposals put forward in recent years with the view to reducing the risk of the ZLB is to increase the inflation target. The model considered in this paper is consistent with this postulate. One of the model features is the neutrality of money in the long term, and in particular the independence of the real interest rate from average inflation. This implies that increasing the inflation target by the central bank should, at least after the transition period, lead to an equivalent increase in the nominal interest rate, and so raise the distance from the lower bound.

This relationship is illustrated numerically in Table 3, where we show, for different levels of the inflation target, the average and quartiles of the distribution of the number of periods after which the economy hits the ZLB when started from the steady state. As in the previous experiment, we estimate these statistics using stochastic simulations, with the model parameters fixed at their posterior means.

With the current inflation target, the ZLB occurs after more than 160 years on average, consistent with the previously reported low probability of the ZLB over the historical sample. Increasing the target by 1 percentage point extends the period to more than 800 years, thus making the problem of the ZLB for interest rates virtually non-existent. However, if the inflation target was reduced to 1.5%, our model implies that the average time to experiencing the ZLB would be slightly more than 21 years. In other words, at least every third recession would trigger problems related to the ZLB for the interest rates.

It is also worth noting that the distribution of the number of periods after which the economy is confronted with the ZLB is clearly skewed – the mean is significantly different from the median. For example, whereas the average time to the ZLB for the interest rates at the inflation target of 1.5% is approximately 21 years, in half of the cases the economy would have to face this situation after less than 15 years, and in every fourth case – after less than 7 years.

5.3. The effects of the ZLB

As we know from the theoretical literature presented in Section 2 and from other countries' experience, getting trapped at the ZLB can imply serious consequences for the economy. In this section, we will use our estimated model to illustrate how the central bank's inability to reduce the interest rate below zero may affect the transmission of key macroeconomic shocks in Poland.

To this end, we will develop a baseline scenario, where our model economy gets trapped at the ZLB for two years. To generate this scenario, we use a sequence of government expenditure shocks. In particular, we assume that for 4 years the economy experiences a sequence of negative fiscal disturbances of a size equal to one standard deviation in each quarter. In this scenario, under the assumption of an initial level of the interest rate at 1%, after two and a half years the economy experiences the ZLB for a period of 2 years, and then comes out of it spontaneously. It should be kept in mind that Poland has not yet faced the ZLB. Hence, it is difficult to point out the most probable scenario leading to such an event. However, our experiments show that the source of shocks used to generate the ZLB scenario does not significantly affect the results discussed in this section. Whereas our selection of disturbances triggering the ZLB is arbitrary, it describes a real-life situation in which a country is forced to suddenly restore its public finance sustainability. Hence, it is a relevant case for a number of countries during the recent financial crisis. Upon this scenario we next impose macroeconomic shocks of the size corresponding to their estimated standard deviation and compare how the response of the economy differs in comparison to normal times when the central bank can freely adjust the interest rate. Figures 3–8 illustrate the impulse responses as percentage deviations from the baseline scenario, except for the interest rate, for which we present its absolute level so that it is clear when the ZLB is binding.

Figure 3 shows the consequences of the ZLB for the propagation of a negative preference shock. This disturbance can be interpreted as a decline in households' propensity to consume, which may be driven, for example, by precautionary motives. This impulse triggers a decline in consumer demand, and consequently a lower level of economic activity and inflation. In normal times (dashed line) the central bank, guided by the objective of stabilising prices and the output gap, counteracts these negative developments caused by the shock by lowering the short-term interest rates. In the ZLB scenario (solid line), no such action is feasible. Non-adjusted interest rates are at the same time conducive to the exchange rate appreciation, amplifying the consequences of the shock. In effect, the decline in output and inflation is clearly deeper, and their return to the baseline scenario much slower compared to normal times.

In a similar way the ZLB amplifies a negative government expenditure shock (Figure 4), a positive risk premium shock, i.e. increased attractiveness of the Polish assets vis-à-vis foreign assets (Figure 5), and a slowdown in economic activity abroad (Figure 6). It is also worth noting that amplification of particular types of shocks is different. Very strong effects occur in the case of a risk premium shock, where in the ZLB scenario the bottom of the GDP decline is about two times deeper and for inflation even three times deeper, than in normal times. In contrast, relatively small differences in GDP response can be observed in the case of government expenditure and foreign GDP shocks. However, in all these cases, the return of output to the baseline path is clearly slower than in times of unconstrained monetary policy.

Interesting conclusions can be drawn from the examination of responses to a positive productivity shock. In normal times, higher production efficiency boosts GDP, which is supported by monetary policy easing in response to a decline in inflation. In the absence of such an adjustment in the interest rate, economic activity does not increase, and in the short term it even declines. A similar result is reported by Neri and Notarpietro (2014).

5.4. Impact of the ZLB abroad

Given the relatively high natural interest rate and inflation target, the probability of the Polish economy hitting the ZLB is limited. In particular, nominal interest rates in Poland remained markedly above zero even in the periods of sharp economic slowdown and deflationary pressure abroad. The situation is different in a number of other economies, including Poland's major trade partner, i.e. the euro area. In that region, due to its relatively high level of economic development, the natural interest rate is lower than in Poland. The European Central Bank's inflation target is also slightly below that adopted by Narodowy Bank Polski. As a result, the euro area is more exposed to the risk of getting trapped by the ZLB than Poland. Due to strong trade and financial linkages, this fact is of non-negligible importance for Poland.

To illustrate the consequences of the euro area experiencing the ZLB for the Polish economy, let us consider an economic crisis in the former, and particularly a scenario where our main trading partner has to struggle with a series of shocks which occurred between 2008 Q3 and 2009 Q2. Figure 8 illustrates the response of the key macroeconomic variables in both countries in a thus defined scenario, while distinguishing between two possible economic conditions in the euro area upon the outbreak of a crisis. In the first one (solid line), the initial level of the short-term interest rate in the euro area is sufficiently high to avoid the ZLB during the crisis. This scenario corresponds to the actual situation from the period between 2008 Q3 and 2009 Q2, when the rates set by the European Central Bank remained clearly above zero. A deep recession abroad (a GDP decrease of 4%) translates into a significant fall in economic activity in Poland, reaching approx. 1.3% at the trough, and a decrease in inflation. Due to aggressive interest rate cuts in the euro area, the exchange rate in Poland significantly appreciates, which additionally contributes to the depth of recession in this country.

In the second variant (dashed line), we assume that the initial interest rate level in the euro area is consistent with its long-term average, i.e. lower than it actually was just before the crisis hit. In this case, it is sufficient for the series of shocks that we used before to push the Eurozone into the ZLB for 2 years. No monetary stimulation options being available, the euro area recovery from the crisis is slower, which is conducive to lowering the economic activity also in Poland. At the same time, however, since a decrease in the nominal interest rates abroad is limited, the real exchange rate changes only slightly and hence does not materially contribute to the deepening of the recession in Poland. Of these two opposing effects, the latter is clearly dominant. As a result, the GDP decline in the Polish economy is clearly shallower when the euro area hits the ZLB, reaching only 1% at the trough.

Summing up, the possibility of our trading partners hitting the ZLB for nominal interest rates to some extent immunises the Polish economy against the crisis scenarios spilling over from abroad. The dominant mechanism in this case is the exchange rate channel, which amplifies the consequences of an imported crisis to a lesser extent than in normal times.

5.5. Effectiveness of fiscal expansion at the ZLB

When the economy experiences the ZLB, conventional monetary policy is not able to accelerate the process of recovery. As shown in the literature discussed in Section 2, an increase in government expenditures then becomes an attractive option as its effectiveness is higher than in normal times.

The main reason for amplification of the effects of such defined fiscal stimulus is the lack of response in the interest rate, which tends to increase in normal times, thus reinforcing the crowding out of private expenditures.

In order to assess the magnitude of amplification of possible fiscal stimulus in Poland at the ZLB, we impose a positive shock of public sector expenditures on the baseline scenario defined in Section 5.2. The scale of the shock is selected so that it does not suffice to steer the economy out of the ZLB before the elapse of a 2-year period, i.e. before the ZLB stops binding in the baseline scenario. Next, we compare the thus obtained impulse responses with those calculated in normal times, i.e. in a situation where interest rates can be freely adjusted by the central bank. To present our results we will use a fiscal multiplier in a discounted version:

$$M_h^d = \frac{\sum_{t=1}^{h} \beta^{t-1}\left(y_t - y_t^s\right)}{\sum_{t=1}^{h} \beta^{t-1}\left(g_t - g_t^s\right)}$$

where y_t and g_t stand for the product and government expenditure paths in the scenarios with an impulse, whereas y_t^s and g_t^s stand for the relevant values of those variables in the baseline scenario ($t = 1,\ldots,h$ where $t = 1$ is the first period of a fiscal impulse, whereas h is the multiplier's horizon).

The results are presented in Table 4. Notwithstanding the horizon and the scenario, the multipliers stand below unity. In other words, an increase in government expenditure by one unit triggers a less than commensurate increase in output. This is because government expenditures in our model have no direct influence on household utility (in contrast to, for example, the provision of public goods by the state) nor on the production capacity (e.g. improvement of infrastructure). Goods purchased by the government are then wholly wasted, whereas the expenses related to their acquisition must ultimately be borne by the taxpayers. In consequence, as government expenditures rise, private demand drops.

From the point of view of the objectives of this paper, it is not the effect itself of fiscal stimulus that is pivotal, but the scale of its amplification during the ZLB episode. The multipliers estimated in Table 4 show that the reinforcement is relatively weak on impact (only 6%), yet very strong if we take a longer horizon into consideration (about twofold for a ten-year horizon). In other words, fiscal stimulus is much more effective in the ZLB conditions than in normal times.

6. Conclusions

This paper discussed the possibility and potential consequences of the ZLB scenario in Poland. The ZLB problem was presented in detail, with particular emphasis on its causes, effects and ways to avoid it. An increase in the inflation target or a switch from inflation targeting to price level targeting were shown, among others, as possible methods of decreasing the risk of hitting the ZLB.

In the empirical part we first assessed the probability and consequences of hitting the ZLB. To this end, we built an open economy DSGE, estimated it using Polish data, and applied it to perform a number of simulations. These showed, among others, that the probability of the ZLB in Poland has

been minor so far. In particular, the current inflation target seems to provide adequate protection against the ZLB. On the other hand, a possible reduction of the target to 1.5% would shift the probability of the ZLB dramatically upwards.

Further simulations confirmed the lessons learned from similar research conducted for other economies, namely, that the ZLB could imply adverse consequences. In particular, some positive disturbances (e.g. a favourable productivity shock) would have a considerably weaker (and potentially even negative) effect on output, whereas some negative disturbances would depress output more in comparison to normal times. On the other hand, the existence of the ZLB for interest rates abroad, at least to some extent, insulates Poland against the effects of a severe crisis originating in other countries. Last but not least, our paper shows a significant increase in the effectiveness of fiscal stimulus at the ZLB.

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Appendix

List of log–linearised model equations

This Appendix provides a full set of loglinearised equations of the model used in the article. These equations include the following variables which are not defined in the main text: the price of capital $P_{k,t}$, the real exchange rate $q_t \equiv e_t P_t^* / P_t$, and the terms of trade $s_t \equiv P_{F,t} / P_{H,t}$. Lowercase marks real counterparts of nominal variables. Symbols with hats denote a logarithmic (absolute in the case of interest rate ι_t and net foreign assets in relation to GDP a_t) deviation from the steady state.

Auxiliary parameters

$$\kappa_h = \frac{(1-\theta_h)(1-\theta_h\beta)}{\theta_h}$$

$$\kappa_f = \frac{(1-\theta_f)(1-\theta_f\beta)}{\theta_f}$$

$$b = \frac{\lambda_w(\varphi+1)-1}{(1-\beta\theta_w)(1-\theta_w)}$$

$$\eta_0 = b\theta_w$$

$$\eta_1 = \varphi\lambda_w - b(1+\beta\theta_w^2)$$

$$\eta_2 = b\beta\theta_w$$

$$\eta_3 = -b\theta_w(1+\delta_w\beta)$$

$$\eta_4 = b\theta_w\delta_w$$

$$\eta_5 = 1-\lambda_w$$

$$\eta_6 = (1-\lambda_w)\varphi$$

$$\frac{\bar{x}}{\bar{y}} = \frac{\alpha\delta}{\beta^{-1}-1+\delta}$$

Consumption and wages

$$(1+\xi)\hat{c}_t = \mathrm{E}_t\hat{c}_{t+1} + \xi\hat{c}_{t-1} + \frac{1-\xi}{\sigma}(\hat{\varepsilon}_{g,t} - \mathrm{E}_t\hat{\varepsilon}_{g,t+1}) - \frac{1-\xi}{\sigma}(\hat{\iota}_t - \mathrm{E}_t\hat{\pi}_{t+1}) \tag{A1}$$

$$\hat{\lambda}_t = \hat{\varepsilon}_{g,t} - \frac{\sigma}{1-\xi}\hat{c}_t + \frac{\sigma\xi}{1-\xi}\hat{c}_{t-1} \tag{A2}$$

$$\eta_6(\hat{l}_t - \hat{\varepsilon}_{l,t}) = \eta_0\hat{w}_{t-1} + \eta_1\hat{w}_t + \eta_2\mathrm{E}_t(\hat{w}_{t+1} + \hat{\pi}_{t+1}) + \eta_3\hat{\pi}_t + \eta_4\hat{\pi}_{t-1} + \eta_5\hat{\lambda}_t \tag{A3}$$

Capital and investment

$$\hat{\lambda}_t + \hat{p}_{k,t} = \beta(1-\delta)\mathrm{E}_t\hat{p}_{k,t+1} + (1-\beta(1-\delta))\mathrm{E}_t\hat{r}_{t+1} + \mathrm{E}_t\hat{\lambda}_{t+1} \tag{A4}$$

$$\hat{Y}_t + \hat{p}_{k,t} = S''(\hat{x}_t - \hat{x}_{t-1}) - \beta S''(\mathrm{E}_t\hat{x}_{t+1} - \hat{x}_t) \tag{A5}$$

$$\hat{k}_{t+1} = (1-\delta)\hat{k}_t + \delta(\hat{Y}_t + \hat{x}_t) \tag{A6}$$

Production and import

$$\hat{y}_t = \hat{z}_t + \alpha\hat{k}_t + (1-\alpha)\hat{l}_t \tag{A7}$$

$$\hat{mc}_t = (1-\alpha)\hat{w}_t + \alpha\hat{r}_t + \omega\hat{s}_t - \hat{z}_t \tag{A8}$$

$$\hat{k}_t + \hat{r}_t = \hat{l}_t + \hat{w}_t \tag{A9}$$

$$(1+\beta\delta_h)\hat{\pi}_{H,t} = \beta\mathrm{E}_t\hat{\pi}_{H,t+1} + \delta_h\hat{\pi}_{H,t-1} + \kappa_h\hat{mc}_t \tag{A10}$$

$$(1+\beta\delta_f)\hat{\pi}_{F,t} = \beta\mathrm{E}_t\hat{\pi}_{F,t+1} + \delta_f\hat{\pi}_{F,t-1} + \kappa_f(\hat{q}_t - (1-\omega)\hat{s}_t) \tag{A11}$$

$$\hat{\pi}_t = \hat{\pi}_{H,t} + \omega(\hat{s}_t - \hat{s}_{t-1}) \tag{A12}$$

$$\hat{s}_t = \hat{\pi}_{F,t} - \hat{\pi}_{H,t} + \hat{s}_{t-1} \tag{A13}$$

Market clearing

$$\hat{\imath}_t - \mathrm{E}_t\hat{\pi}_{k,t+1} = \hat{\imath}_t^* - \mathrm{E}_t\hat{\pi}_{k,t+1}^* + \mathrm{E}_t\hat{q}_{t+1} - \hat{q}_t - \chi\hat{a}_t - \hat{\phi}_t \tag{A14}$$

$$\hat{\tilde{y}}_t = \left(1 - \frac{\bar{x}}{\bar{y}} - \frac{\bar{g}}{\bar{y}}\right)\hat{c}_t + \frac{\bar{x}}{\bar{y}}\hat{x}_t + \frac{\bar{g}}{\bar{y}}\hat{g}_t \tag{A15}$$

$$\hat{y}_t = \eta\omega(\hat{s}_t + \hat{q}_t) + \omega\hat{y}_t^* + (1-\omega)\hat{\tilde{y}}_t \tag{A16}$$

$$\hat{a}_t = \frac{1}{\beta}\hat{a}_{t-1} - \omega(\hat{q}_t + \omega\hat{s}_t) + \hat{y}_t - \hat{\tilde{y}}_t \tag{A17}$$

Monetary policy

$$\hat{\imath}_t = \max\{-\bar{\imath}; \psi_i\hat{\imath}_{t-1} + (1-\psi_i)[\psi_y\hat{y}_t + \psi_p\hat{\pi}_t + \psi_{dp}(\hat{\pi}_t - \hat{\pi}_{t-1})] + \sigma_m\varepsilon_{m,t}\} \tag{A18}$$

List of model variables

Variable	Definition
$\hat{c}_t$	Consumption
$\hat{\imath}_t$	Nominal interest rate
$\hat{\lambda}_t$	Lagrange multiplayer on household budget constraint
$\hat{w}_t$	Real wage
$\hat{\pi}_t$	Inflation
$\hat{l}_t$	Labour
$\hat{x}_t$	Investment
$\hat{p}_{k,t}$	Real price of capital
$\hat{r}_t$	Rental rate on capital
$\hat{k}_t$	Capital
$\hat{y}_t$	Output
$\widehat{mc}_t$	Real marginal cost
$\hat{s}_t$	Terms of trade
$\hat{\pi}_{H,t}$	Inflation of home goods
$\hat{\pi}_{F,t}$	Inflation of foreign goods
$\hat{q}_t$	Real exchange rate
$\hat{a}_t$	Net foreign assets in relation to steady-state output
$\hat{g}_t$	Government expenditures
$\hat{\imath}_t^*$	Foreign nominal interest rate
$\hat{\pi}_t^*$	Foreign inflation
$\hat{y}_t^*$	Foreign output
$\hat{\tilde{y}}_t^*$	Domestic demand
Shocks	
$\hat{y}_{m,t}$	Monetary shock
$\hat{\phi}_t$	Risk premium shock
$\hat{z}_t$	Productivity shock
$\hat{Y}_t$	Investment specific shock
$\hat{\varepsilon}_{l,t}$	Labour supply shock
$\hat{\varepsilon}_{g,t}$	Preference shock
$\hat{g}_t$	Government expenditure shock
$\hat{\varepsilon}_{y^*,t}$	Foreign GDP shock (VAR)
$\hat{\varepsilon}_{i^*,t}$	Foreign interest rate shock (VAR)
$\hat{\varepsilon}_{p^*,t}$	Foreign inflation shock (VAR)

Hats denote log deviation from the steady state.
All domestic shocks are AR(1) processes, except for the monetary shock that is white noise. Foreign shocks are modelled as a VAR(2) process.

Data description

Variable	Name	Source	Transformations
y	Gross domestic product at market prices	Eurostat, ESA2010	Log deviation from HP trend. Seasonally adjusted with TRAMO/SEATS
c	Final consumption expenditure	Eurostat, ESA2010	Log deviation from HP trend. Seasonally adjusted with TRAMO/SEATS
x	Gross capital formation	Eurostat, ESA2010	Log deviation from HP trend. Seasonally adjusted with TRAMO/SEATS
π	HICP	Eurostat	Inflation rate of HICP index. Data transformed to quarterly frequency from monthly using standard Eviews procedure. Deseasoned with Eviews TRAMO/SEATS
w	Average real gross monthly wage	GUS, Eurostat	Deflated with HICP. Seasonally adjusted with TRAMO/SEATS
ι	3m money maret rate	Eurostat	Quarterly average of montly rate
ι^*	3m money maret rate (euro area)	Eurostat	Quarterly average of montly rate
y^*	Gross domestic product at market prices (euro area, 18 countries)	Eurostat, ESA2010	Log deviation from HP trend
π^*	HICP (euro area, 18 countries)	Eurostat	Inflation rate of HICP index. Data transformed to quarterly frequency from monthly using standard Eviews procedure. Deseasoned with Eviews TRAMO/SEATS
q	Real euro/zloty exchange rate	Eurostat, own calculations	Converted to real terms using HICP indexes for Poland and the euro area

Table 1
Calibration

Parameter	Value	Definition
β	0.99	Discount factor
α	0.30	Capital share
χ	0.01	Risk premium elasticity with respect to foreign debt
δ	0.02	Capital depreciation rate
λ_w	1.20	Wage markup
$\bar{g}/\bar{y}$	0.185	Steady-state ratio of government expenditure to GDP
ω	0.28	Steady-state share of imports in GDP

Table 2
Estimation results

Parameter	Type	A priori		A posteriori			Definition
		average	standard deviation	average	5%	95%	
σ	Normal	2	0.5	2.09	1.42	2.77	Inverse of intertemporal elasticity of substitution
ϕ	Normal	2	0.5	2.18	1.42	2.93	Inverse of Frisch elasticity
θ_f	Beta	0.6	0.1	0.595	0.49	0.694	Calvo parameter for domestic goods
θ_h	Beta	0.6	0.1	0.81	0.75	0.87	Calvo parameter for foreign goods
θ_w	Beta	0.6	0.1	0.596	0.47	0.71	Calvo parameter for wages
ξ	Beta	0.7	0.05	0.76	0.69	0.82	Consumption habits
η	Normal	1.5	0.5	0.50	0.45	0.56	Elasticity of substitution between domestic production and imports
δ_h	Beta	0.5	0.1	0.48	0.32	0.64	Domestic price indexation
δ_f	Beta	0.5	0.1	0.54	0.37	0.69	Foreign price indexation
δ_w	Beta	0.5	0.1	0.53	0.38	0.69	Wage indexation
ψ_i	Beta	0.8	0.1	0.92	0.90	0.94	Inertia in the Taylor rule
ψ_p	Normal	2	0.1	2.01	1.85	2.17	Response to inflation in the Taylor rule
ψ_y	Normal	0.125	0.05	0.095	0.016	0.17	Response to GDP in the Taylor rule
ψ_{dp}	Normal	0.3	0.1	0.25	0.087	0.41	Response to change in inflation in the Taylor rule
S''	Normal	5	1.0	4.14	2.45	5.67	Second derivative of investment adjustment cost function in the steady state
ρ_z	Beta	0.75	0.1	0.71	0.57	0.85	Productivity shock autocorrelation
ρ_g	Beta	0.75	0.1	0.83	0.75	0.91	Consumption preference shock autocorrelation
ρ_l	Beta	0.75	0.1	0.44	0.31	0.58	Labour preference shock autocorrelation
ρ_γ	Beta	0.75	0.1	0.69	0.58	0.81	Investment shock autocorrelation
ρ_φ	Beta	0.75	0.1	0.86	0.78	0.92	Risk premium shock autocorrelation
ρ_G	Beta	0.75	0.1	0.85	0.79	0.91	Government expenditure shock autocorrelation
σ_z	Inverse gamma	0.01	∞	0.016	0.0098	0.0221	Standard deviation of productivity shock
σ_g	Inverse gamma	0.01	∞	0.0399	0.0256	0.0536	Standard deviation if consumption preference shock
σ_l	Inverse gamma	0.01	∞	0.3471	0.1127	0.5457	Standard deviation of labour preference shock
σ_γ	Inverse gamma	0.01	∞	0.0595	0.034	0.0839	Standard deviation of investment shock

σ_{φ}	Inverse gamma	0.01	∞	0.0072	0.0042	0.0102	Standard deviation of risk premium shock
σ_{m}	Inverse gamma	0.001	∞	0.0012	0.00097	0.0014	Standard deviation of monetary shock
σ_{G}	Inverse gamma	0.01	∞	0.0515	0.0422	0.0607	Standard deviation of government expenditure shock

Table 3
The number of quarters until hitting the ZLB

Inflation target	Average	1st quartile	Median	3rd quartile
1.5%	85. 1	26	59	118
2.5%	802.1	237	551	1111
3.5%	4672.3	1330	3237	6498

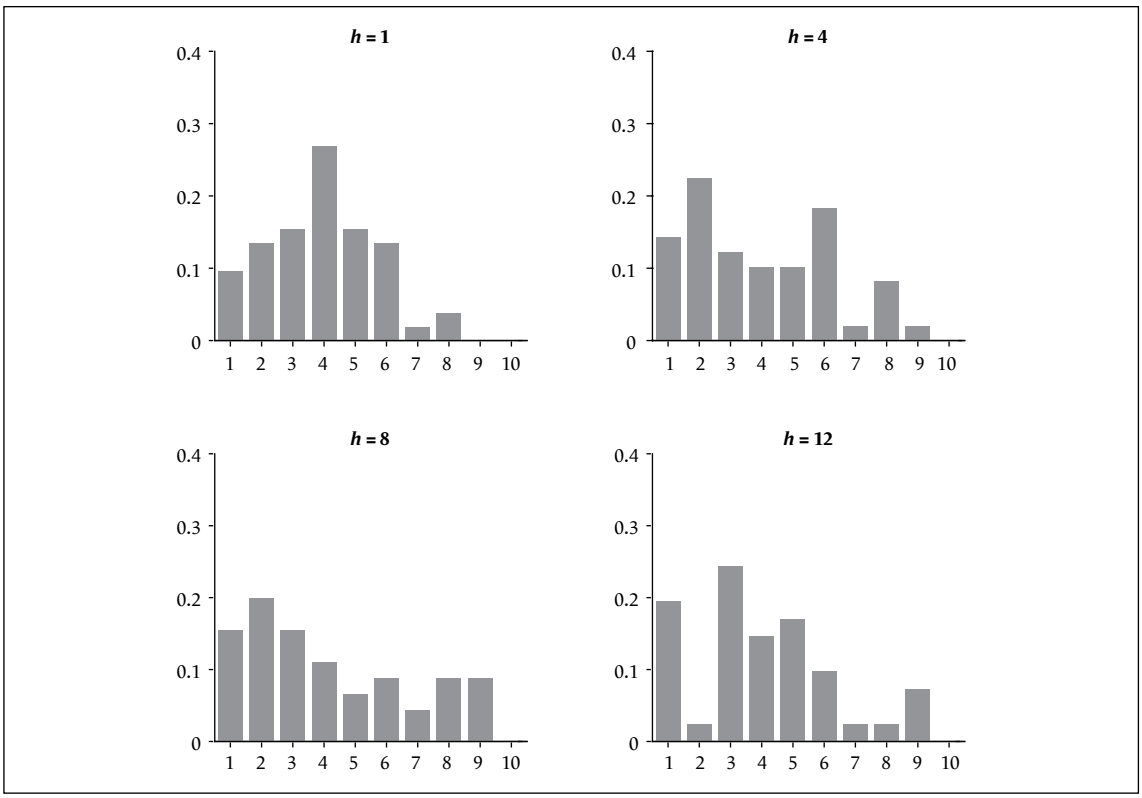
Notes: the table presents the distribution characteristics of the number of quarters until the Polish economy faces the ZLB, for different levels of the inflation target.

Table 4
Fiscal multipliers in normal times and in the ZLB

h	Normal times	ZLB	Amplification ratio
1	0.66	0.70	1.06
4	0.55	0.68	1.24
8	0.45	0.67	1.49
12	0.34	0.59	1.74
20	0.32	0.56	1.75
40	0.24	0.47	1.96

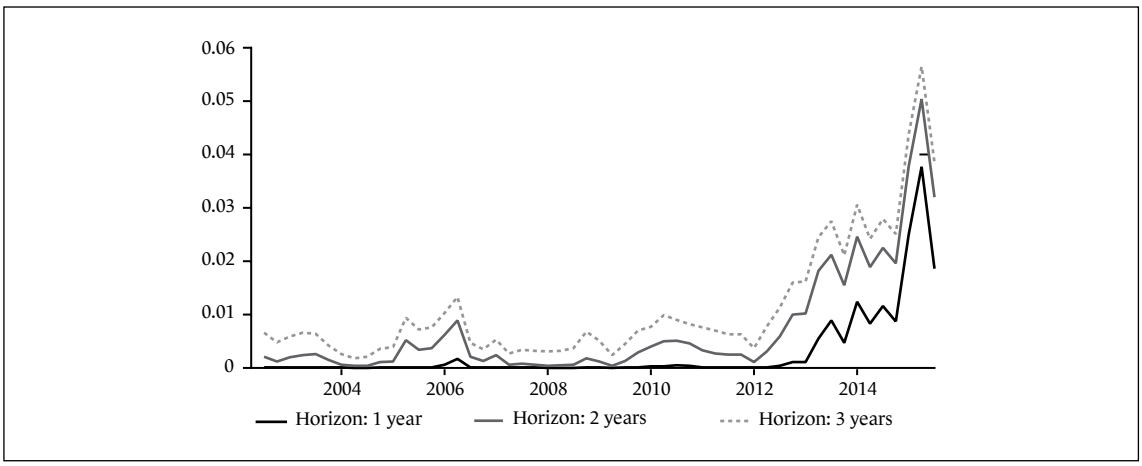
Notes: fiscal multipliers are defined as the ratio of the discounted sum of output deviations from the baseline scenario and the discounted sum of government expenditure deviations within the period covered by horizon *h*. The amplification factor is defined as a ratio of a given multiplier in the ZLB to its counterpart in normal times. The multipliers concern the fiscal impulse, defined as a positive shock in the process describing government expenditures. The shock size is such that in the ZLB scenario the zero lower bound for nominal interest rates is binding for the two first years of the impulse.

Figure 1
PITs for the interest rate in Poland



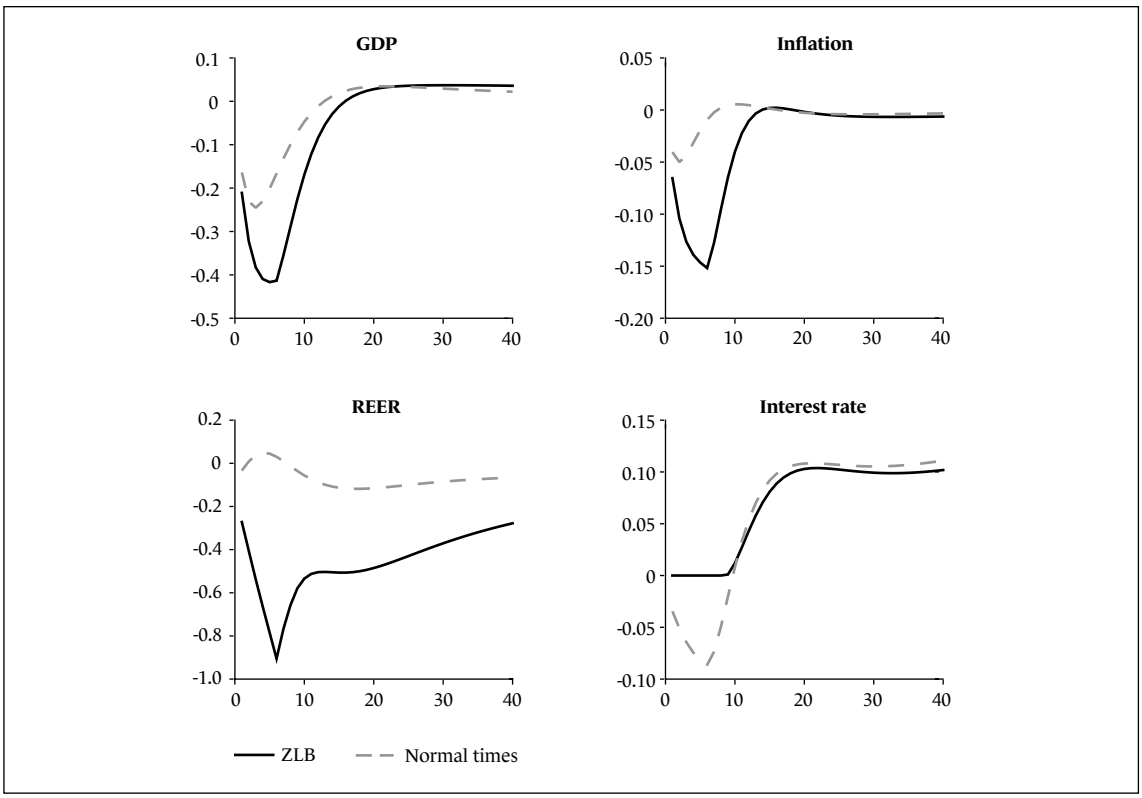
Notes: the graphs show the frequency of the actual interest rates in Poland hitting the particular deciles of the predicitve distribution implied by the estimated DSGE model at different forecast horizons.

Figure 2
The probability of hitting the ZLB in Poland



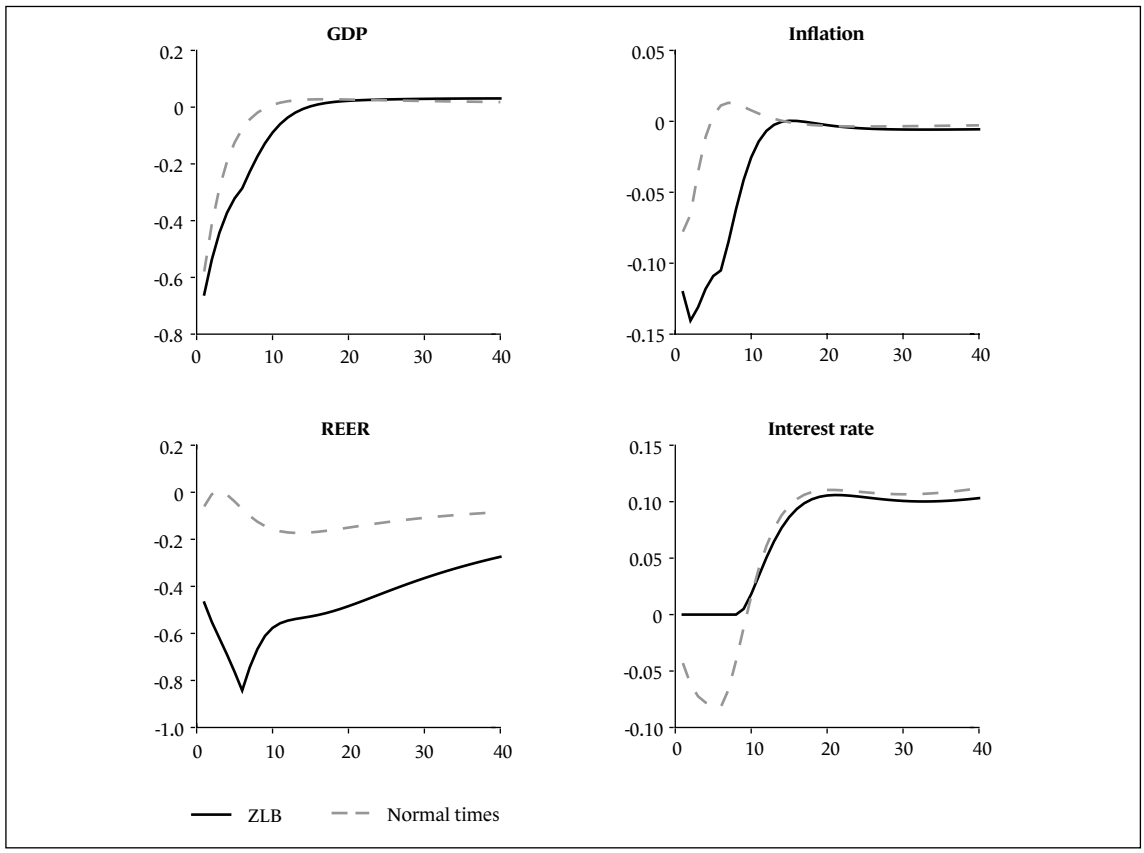
Notes: the lines on the graph show the probability of the Polish economy hitting the ZLB over three different time horizons. The probabilities are based on stochastic simulations with the model parameters set to their posterior means and conditional on the state of the economy in the quarter indicated on the horizontal axis.

Figure 3
Response to a negative preference shock at the ZLB



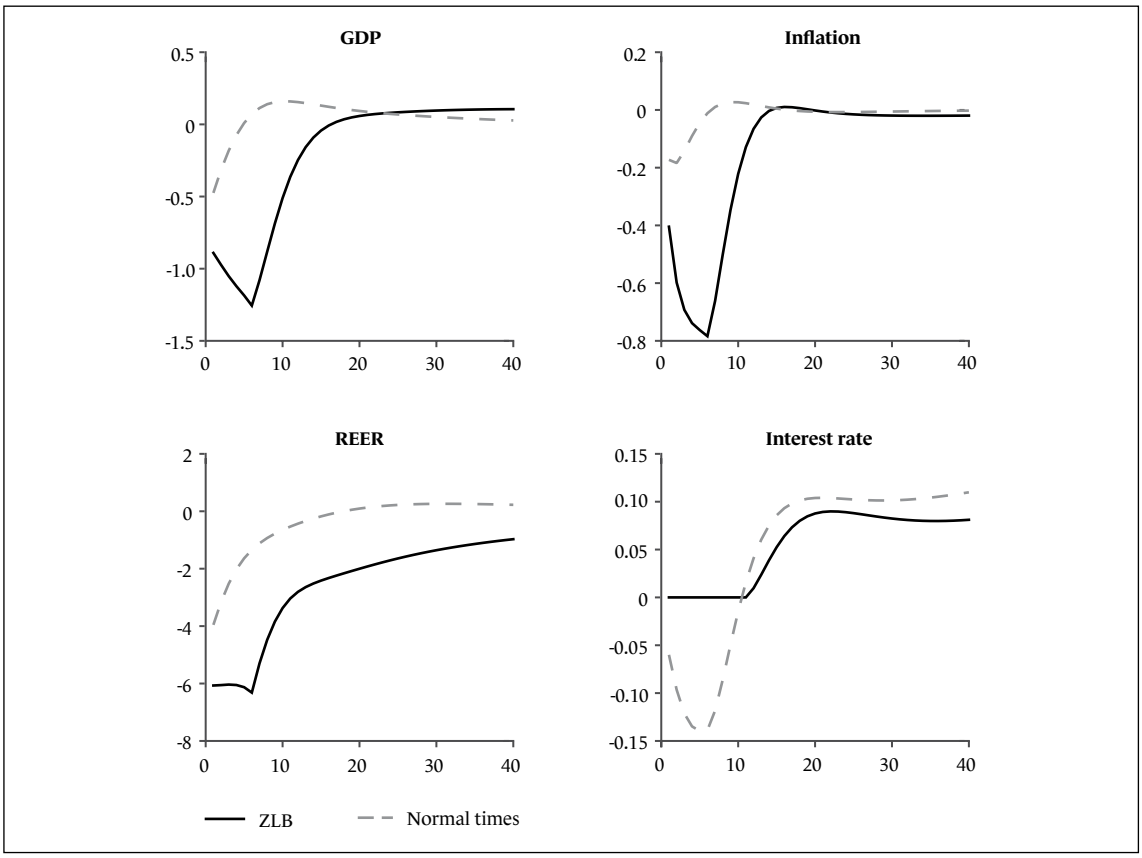
Notes: the responses of GDP, inflation and the exchange rate are expressed as percentage deviations from the baseline scenario. For the interest rate, its absolute level is presented.

Figure 4
Response to a negative government expenditure shock at the ZLB



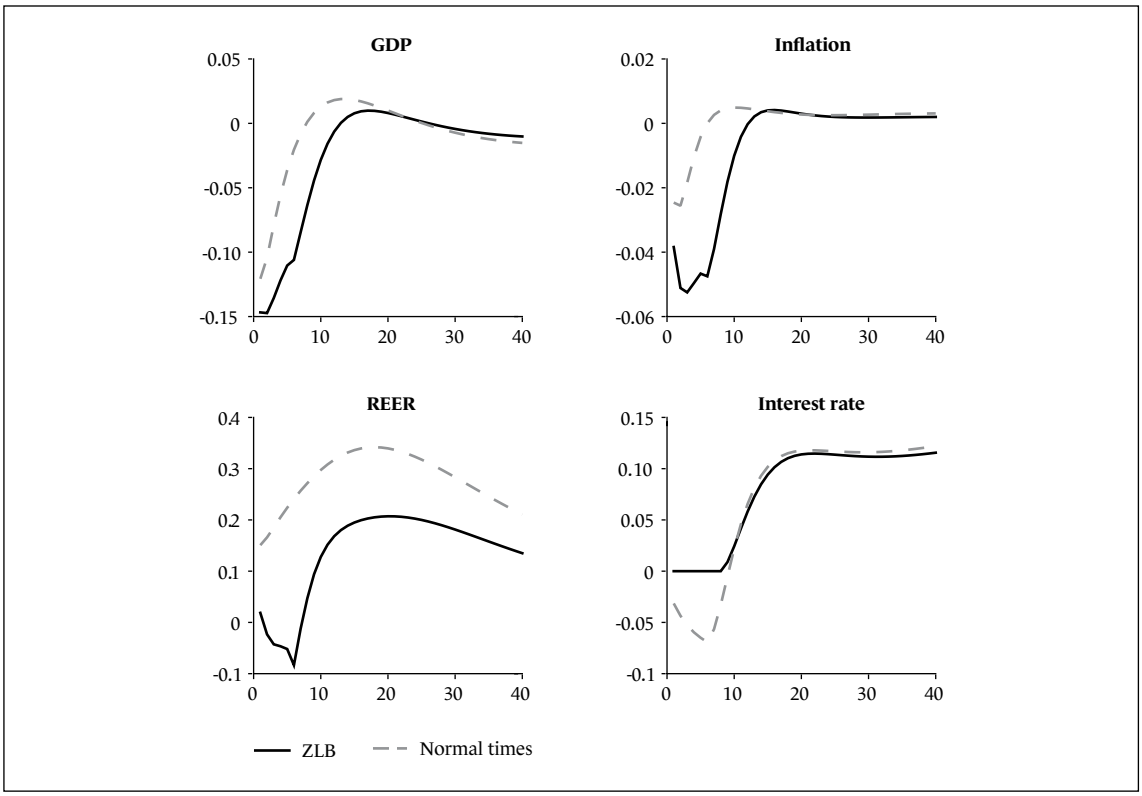
Notes: the responses of GDP, inflation and the exchange rate are expressed as percentage deviations from the baseline scenario. For the interest rate, its absolute level is presented.

Figure 5
Response to a positive risk premium shock at the ZLB



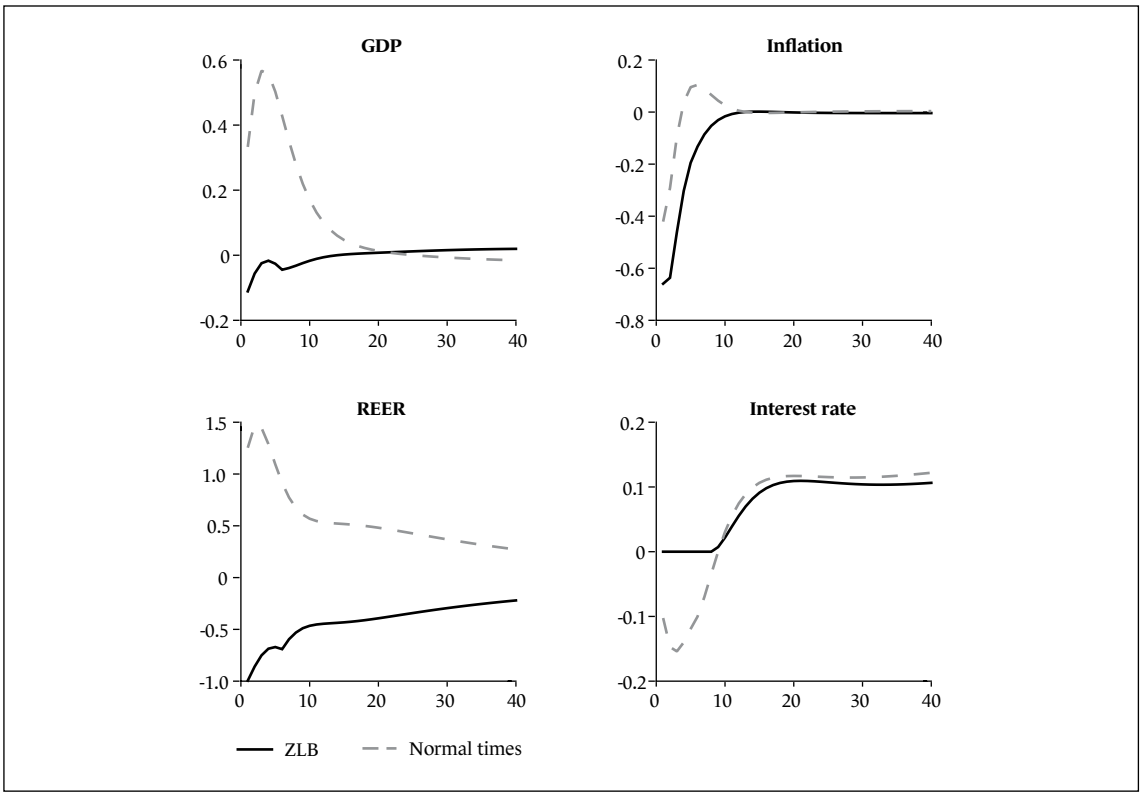
Notes: the responses of GDP, inflation and the exchange rate are expressed as percentage deviations from the baseline scenario. For the interest rate, its absolute level is presented.

Figure 6
Response to a negative GDP shock abroad at the ZLB



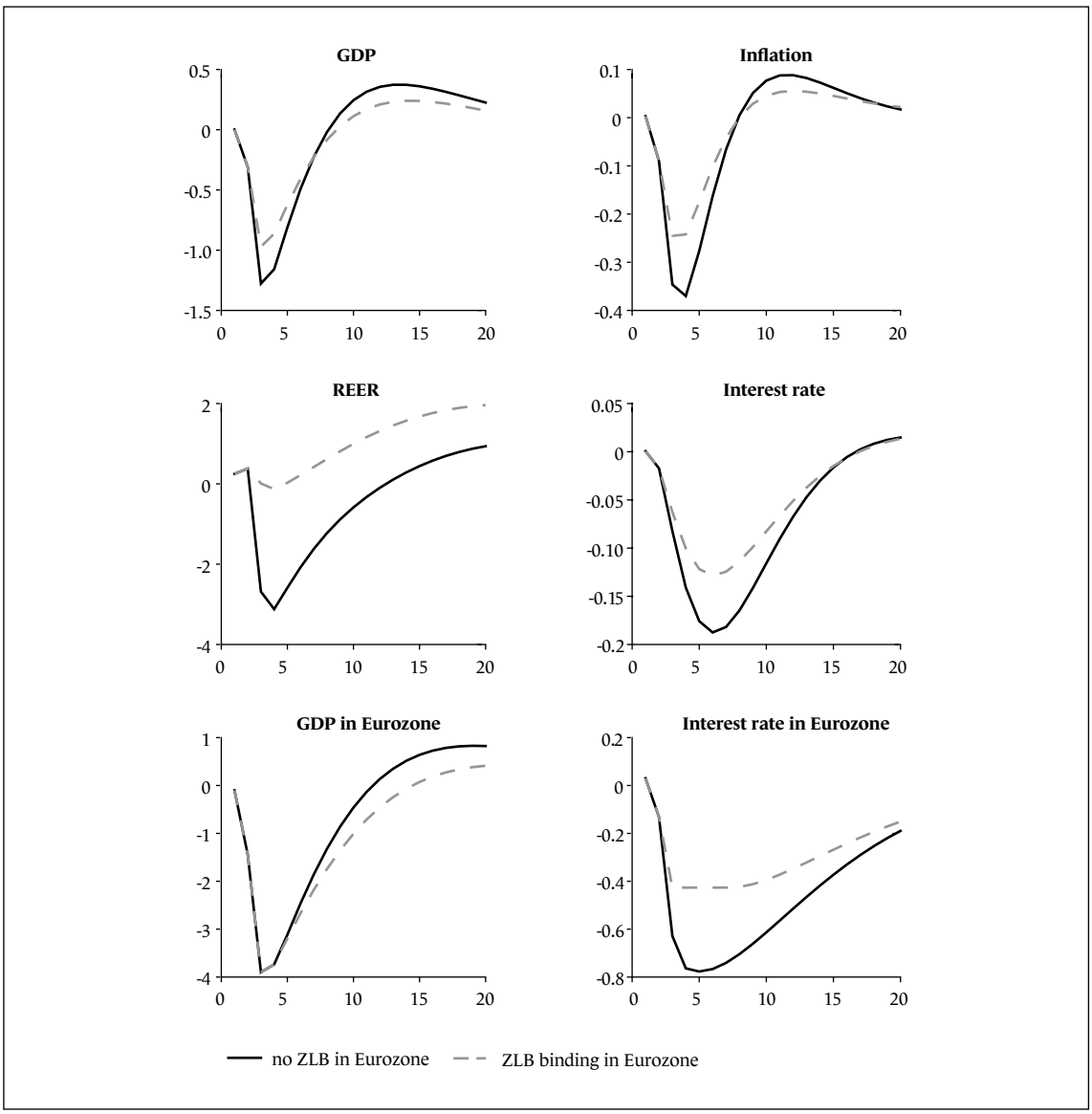
Notes: the responses of GDP, inflation and the exchange rate are expressed as percentage deviations from the baseline scenario. For the interest rate, its absolute level is presented.

Figure 7
Response to a positive productivity shock at the ZLB



Notes: the responses of GDP, inflation and exchange rate are expressed as percentage deviations from the baseline scenario. For the interest rate, its absolute level is presented.

Figure 8
Transmission of the crisis under the ZLB abroad



Notes: the responses of GDP, inflation and exchange rate are expressed as percentage deviations from the baseline scenario. For the interest rate, its absolute level is presented.