Do long term interest rates drive GDP and inflation in small open economies? Evidence from Poland*

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Abstract

I show that the long term interest rate that includes a time-varying term premium stabilizes GDP and it does not affect significantly inflation volatility in Poland. I derive this result from an estimated DSGE model of a small open economy. GDP volatility would have been much higher if the endogenous part of the term premium had been switched off in the model, while the inflation volatility has not been affected by the presence of the term premium. At the same time, the term premium shock had only a minor impact on GDP and inflation volatilities which suggests that the QE programs conducted by the major central banks did not have a substantial impact on the Polish economy.

JEL: E32, E43, E44

Keywords: long term interest rates, time-varying term premium, business cycle, small open economy

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1 Introduction

The long term interest rate is an important variable for the dynamics of the business cycle in a small ope economy (SOE). It affects the consumption and saving's decisions of households. If we associate the long term interest rate with a government bond yield, it also constitutes the government borrowing cost. In this way the long term interest rate also influences fiscal policy. If a government bond is purchased by a foreign investor, then the long term interest rate may also affect the exchange rate. Financial investors usually perceive long term government bonds as attractive investments in SOEs since they bear relatively low credit and liquidity risks. If the risk-adjusted yields in the SOE are relatively high compared to other economies, investors searching for yield will buy government bonds in this SOE which may be conducive to the appreciation of its exchange rate. In contrast, in times of heightened risk aversion in the global financial markets, investors will sell out government bonds contributing to the SOE's currency depreciation. From the central bank's point of view this reasoning implies that the long term interest rate has a substantial impact on two main channels of the monetary policy transmission mechanism in the SOE: the interest rate and the exchange rate channels.

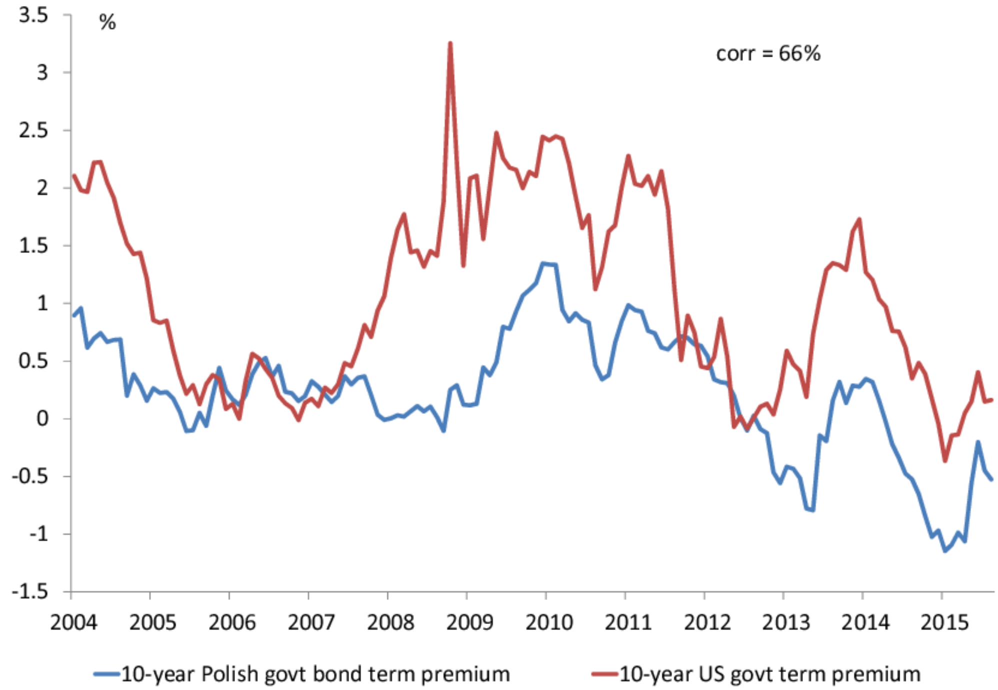
Despite the impact of the long term interest rate on the business cycle and its role for the monetary policy, estimated macroeconomic general equilibrium models of SOEs do not explicitly include the long term interest rate [1]. As a result these models implicitly assume that the Expectations Hypothesis (EH) does hold, i.e. the long term interest rate equals the expected path of the short term rates. A dominant explanation for the invalidity of the EH is the presence of the time-varying term premium in the long term interest rate and there is a vast literature that models it (Adrian et al. 2013, Doh 2011, Bekaert et al. 2010, Piazzesi 2010, De Graeve et al. 2009, Smith and Taylor 2009, Rudebusch and Wu 2007, Diebold et al. 2006). These models allow to extract the term premium by dividing the yield into two components: the expected average short term interest rate and the term premium that investors require for holding a multiperiod asset instead of rolling over a one-period asset.

In this article I attempt to fill the gap in the literature that has not investigated the role of the long term interest rate in an SOE. To this end I analyze the impact of the time-varying term premium on GDP and inflation fluctuations in an SOE over a business cycle. I construct a structural macroeconomic model of an SOE that explicitly accounts for the time-varying term premium and I estimate this model with the Polish and euro area data. Although the Polish economy may differ appreciably from other SOEs in many respects, I attempt to draw some conclusions for other SOEs basing on this particular case.

In order to motivate this research topic I build on the existing literature that has verified

[1] There have been recently some attempts to include term premium in simulated models, however, see e.g. Alpanda and Kabaca (2015)

Figure 1: The term premium in Polish and US government bonds



Source: New York Fed (the term premium in the US), estimation based on Adrian et al. (2013) (the term premium in Poland)

the EH[2] and I formally show in section 2 that the EH assumption is unwarranted in Poland in the time horizon above one year. Furthermore, I use the model of Adrian et al. (2013) to estimate the term premium in Poland and I compare it with the original estimates for the US[3]. It turns out that in the world of integrated financial markets the term premium in the US and Poland are strongly correlated (Figure 1). Thus, I claim that estimated dynamic stochastic general equilibrium (DSGE) models of the Polish economy unrecognizing the time-varying term premium may omit a potentially important link between Polish and external economies.

The invalidity of the EH and the high correlation between term premia in Poland and the US motivate me to investigate whether this variable is important for dynamic properties of the Polish economy, economic policies in this economy and its linkages with external economies. I find the role of long term interest rates and term premia interesting both from theoretical (better understanding of economic dynamics) and practical (in particular the effectiveness of monetary policy) points of view. Therefore, in this paper I address the

[2]See Gürkaynak and Wright (2012) for a review and Sarno et al. (2007), Bekaert et al. (2001), Campbell and Shiller (1991), Fama and Bliss (1987) for well-known examples.

[3]http://www.newyorkfed.org/research/data_indicators/term_premia.html

following four questions:

- Does the term premium in the long term interest rate significantly affect the shock propagation mechanism in the SOE?
- Does the term premium significantly impact the volatility of output gap and inflation in the SOE?
- Did changes in investors' sentiment (e.g. associated with the QE programs) affect GDP and inflation in Poland?
- What is the estimated impact of long-term interest rates on GDP as compared with the impact of short term interest rates in Poland?

My contribution to the existing literature is to address these questions that - to the best of my knowledge - have not been investigated yet. Furthermore, my contribution is to explicitly account for the time-varying term premium in an estimated structural economic model of an SOE.

I proceed as follows. I verify the EH for Poland in section 2. In section 3, building on the existing literature that investigated the role of the long term interest rate in a large closed economy, I construct the SOE New Keynesian (NK) DSGE model that accounts for the time-varying term premium. In section 4 I estimate this model with the Polish and the euro area data in order to assess the impact of the long-term interest rate on GDP and inflation. In section 5 I perform a set of simulations, decompositions and impulse response functions and I show that the time-varying term premium stabilizes GDP in Poland and is an important variable in shock propagation. Finally, section 6 concludes.

2 Motivating evidence: the failure of the Expectations Hypothesis

In this section I test the EH in Poland applying simple regressions that go back to Fama and Bliss (1987).

2.1 The Expectations Hypothesis

The EH of the nominal interest rates (yield curve) is usually formulated in the following way:

$$y_0^{(N)} = \frac{1}{N} E(y_0^{(1)} + y_1^{(1)} + y_2^{(1)} + ...y_{N-1}^{(1)})(+risk\ premium) \tag{1}$$

where $y_t^{(N)}$ stands for the yield of the N-period zero coupon bond quoted at the time t. According to this formula, the N-period interest rate at time 0 is equal to the sum of expected short term (one-period) interest rates at times: 0, 1, ..., N-1 plus a risk premium that is constant over time. This is no arbitrage condition as it states that at period 0 two ways of getting the return from time 0 to N should give the same return: either by buying an N-period bond or rolling over 1-period bonds (buying forward contracts for 1-period bonds) for N periods. This formulation of the EH is of particular importance from the monetary policy point of view. If the central bank's rule relating monetary policy to macroeconomic conditions (e.g. output gap and inflation rate) were known to investors, then one could also imply from the yield curve their expectations about the future state of the economy (Gürkaynak and Wright 2012).

In order to verify the EH the following model is estimated in the literature (such regressions go back to Fama and Bliss (1987) and are often called Fama-Bliss estimations (see also Backus et al. (2001), Duffee (2002), and Cochrane and Piazzesi (2005)):

$$y^{(1)}_{t+N-1} - y^{(1)}_t = a + b(f^{(N)}_t - y^{(1)}_t) + \epsilon_{t+N-1} \tag{2}$$

where $f^{(N)}_t$ is a 1-period forward rate from period. This one-equation econometric model is derived from an equivalent formula to eq. 1 and is estimated with a standard OLS method.[4]

2.2 The EH verification for Poland

Due to data availability I divide the estimation into two subestimations: for short term horizon (up to one year) and medium term horizon (above one year).

[4]The estimation procedure is subject to some econometric issues. They fall into four categories: endogeneity, small sample, structural change and non-representative sample (Gürkaynak and Wright 2012). I address the first issue by performing the GMM estimation as a robustness check for the baseline estimation, taking lagged forward rates as an instrument variable. It turns out, that conclusions based on OLS and GMM estimations are coherent. As for the second issue, Bekaert et al. (1997) show that in case of a bias resulting from the persistence in short term interest rates the test statistics reject the EH more strongly if they are evaluated with small-sample distributions as compared with the asymptotic distributions. This implies that OLS based on asymptotic distributions will not reject the EH in more cases then the "correct" estimation based on small-sample distribution. Thus, rejecting the EH with OLS estimator implies rejecting it with small-sample estimators. The third issue is associated with the so called "peso problem" that refers to a situation in which bond yields are priced in a way that accounts for the possibility of a regime shift that was not observed in the short sample (see e.g. Bekaert et al. 2001).Since my sample includes the global financial crisis, it contains the regime switch that is very likely to matter for bond prices. Thus, my estimations should not be influenced by the "peso problem". Finally, it is argued that the articles that verify the EH with postwar U.S. data use too narrow data set. Summing up arguments of this kind Gürkaynak and Wright (2012) notice that the EH tends to be supported by the data if inflation expectations are well-anchored, inflation uncertainty is low and the central bank does not smooth interest rates so that they can be well-approximated by a random walk specification. My sample seems to meet these requirements. It is characterized by relatively (on historical standards) stable inflation expectations that can be read from the data. Furthermore, the record of low and stable inflation during the sample period together with stable long term interest rates suggest low inflation uncertainty.

Table 1: Fama-Bliss estimation. Short term horizon

Time horizon (N [quarters])	b estimate	90% confidence interval for b
2	1.050	(0.897; 1.204)
3	1.097	(0.940; 1.255)
4	1.152	(0.967; 1.336)

2.2.1 Short term horizon

Firstly, I focus on the short-term horizon. I use monthly data on the 3-month interest rates in the Polish interbank market (WIBOR) and forward contracts on these interest rates. The data set spans the period from 2004M01 to 2014M12. In order to verify the EH formally I estimate the following model given by eq. 2 for N = 2,3,4 quarters. The dependent variable $(y^{(1)}_{t+N-1} - y^{(1)}_t)$ is the difference between 3-month WIBOR observed in the interbank market N-1 quarters in the future from time t and 3-month interest rate at time t. The independent variables include: a constant and the difference $(f^{(N)}_t - y^{(1)}_t)$ between the forward rate at time t on 3-month WIBOR N-1 quarters in the future from time t and 3-month interest rate at time t.

Table 1 reports the estimates for b's. Expectation hypothesis for interest rates can not be rejected in the time horizon up to 1 year as the confidence intervals for time horizons of 2,3 and 4 quarters cover 1 (even though point estimates are increasingly far away with the length of time horizon).

2.2.2 Medium term horizon

As the liquid contracts for forward rates in the interbank market for the time horizon above one year are not available in the analyzed period, I use interest rate swap contracts to analyze the EH in the longer horizon in the period 2004M01 to 2014M12. I estimate eq. 2 for N = 2, 3, 4 and 5 years taking as dependent variable $(y^{(1)}_{t+N-1} - y^{(1)}_t)$ the difference between 1-year swap rate observed in the market N-1 years in the future from time t and 1-year swap rate at time t. Furthermore, the independent variables consist of a constant and the difference $(f^{(N)}_t - y^{(1)}_t)$ between synthetic forward rates N-1xN years observed N-1 years in the future from time t and 1-year swap rate at time t.

Table 2 presents the results of the Fama-Bliss estimation for the medium term horizon. I reject the EH in the horizon above one year. This means that investors were not forming their expectations according to the EH in the medium term.

The partial failure of the EH in Poland is in line with the broad evidence found in literature. I reject empirically the EH of the interest rates in Poland for a time period above 4 years. Importantly, the term structure equation I reject is implicitly included in a standard

Table 2: Fama-Bliss estimation. Medium term horizon

Time horizon (N [years])	b estimate	90% confidence interval for b
2	1.339	(1.053; 1.625)
3	1.281	(0.999; 1.564)
4	0.234	(-0.110; 0,579)
5	0.103	(-0.139; 0.345)

NK DSGE model. Thus, as I confirm empirically, these models lack a potentially important feature - deviations from the EH.

3 The Model

I construct the SOE New Keynesian (NK) DSGE model that accounts for the time-varying term premium building on the existing literature that investigated the role of the long term interest rate in a large closed economy. In this literature DSGE models attempt to account for the time-varying term premium in two ways. Some derive the model equations as a third-order approximation around the steady state (Fernández-Villaverde et al. 2010, Rudebusch and Swanson 2008). However, in these models it is difficult to obtain a significant impact of the term premium on consumption and output (Gürkaynak and Wright, 2012). Secondly, the computation of a third order approximation is much more time-consuming than that of standard linearized models and its estimation is currently impossible (Rudebusch et al., 2007; Andreasen and Zabczyk, 2011). Thus, bringing non-linearized DSGE models to the data is much more difficult. Therefore, other papers attempt to include the time-varying term premium by augmenting the DSGE model with imperfect asset substitutability and bond market segmentation (Kiley 2014, Chen et al. 2012, Falagiarda and Marzo 2012, Andrés et al. 2004). It is noteworthy, that imperfect asset substitutability is not an ad hoc assumption, as it is well-grounded in economic literature. It has been advocated for a long time - Tobin criticized macroeconomic models in which "all non-monetary assets and debts are taken to be perfect substitutes at a common interest rate plus or minus exogenous interest differentials" (Tobin 1969).

I follow the latter approach and introduce imperfect asset substitutability and bond market segmentation. To this end I include three types of bonds modeled explicitly in the economy: domestic short term bond, domestic long term bond and foreign long term bond. Furthermore, I divide households into two subgroups that are differentiated by their access to bonds markets. Unrestricted households can purchase/ issue all types of bonds available in the modeled economy, but they have to pay transaction and adjustment costs issuing/buying long term assets. Restricted households, in turn, can purchase/ issue only long-term domestic

Table 3: Households and their access to bond markets

	Unrestricted Households	Restricted Households
Domestic short term	✓	
Domestic long term	✓	✓
Foreign long term	✓	

Table 4: Correlations between term premia and international investment positions to GDP (deviations from a linear trend)

	correlation	p-value (H0: no correlation)
Czech Republic	-0.45	0.01
Hungary	-0.05	0.73
South Korea	-0.37	0.01
Poland	-0.58	0.00
Sweden	-0.09	0.50
Australia	0.27	0.04
New Zealand	-0.32	0.02

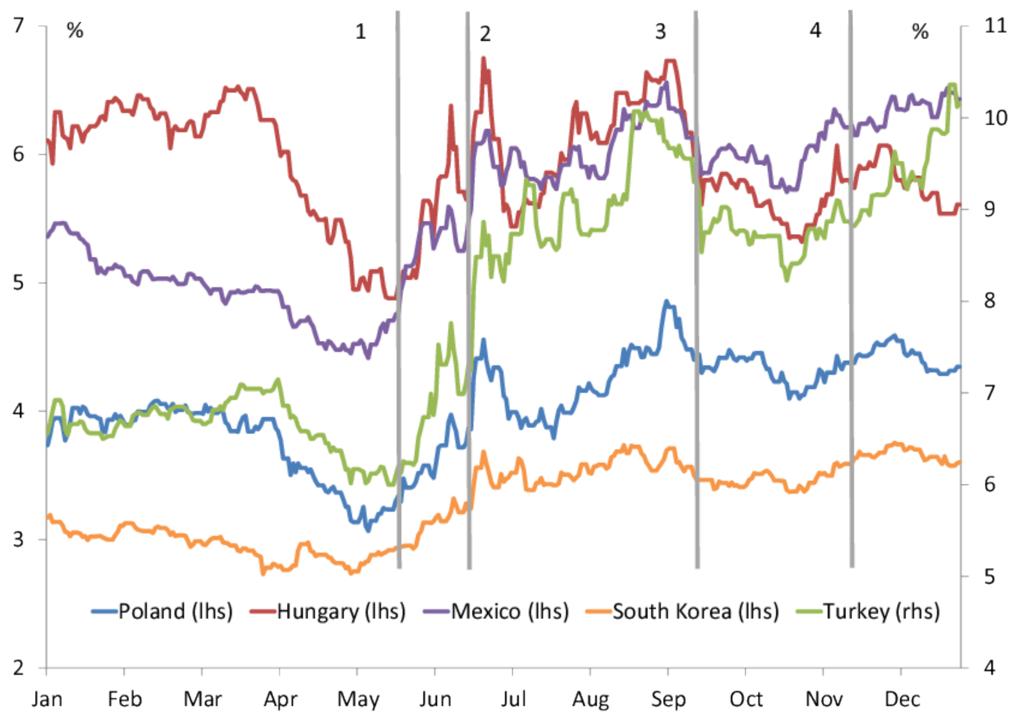
Source: Estimations based on Adrian et al. (2013)

bonds without bearing any costs (see Table 3).

This convention is based on the literature (see Andrés et al. 2004; Kiley 2014; Chen et al. 2012) where it is thoroughly explained that modeling two types of households with different access to asset markets is a useful and comprehensive way to introduce market segmentation and imperfect asset substitutability. These models were derived to analyze the consequences of the central bank bond purchases in a large closed economy. This is reflected in the way the term premium is modeled in these models - it depends on endogenous factors such as money holdings, long term bonds issued by the government to finance its deficit as well as exogenous factors. In an SOE, however, endogenous factors that impact the term premium may include also the external debt. External imbalances influence the long term interest rate because investors are worried about the sustainability of external debt and require a compensation for the risk they take. They may be more suitable to analyze the term premium determinants than e.g. public debt since the level of fiscal debt may not correctly reflect underlying fiscal vulnerabilities (Gros 2011). Indeed, data suggests that countries with higher external net debt are characterized by higher yields on long term bonds. Table 4 confirms negative relationship between net asset position and term premia for SOEs showing usually negative and statistically significant correlation between the estimated term premium for SOEs and net international investment positions. Therefore, I allow unrestricted households to also trade in foreign long term bonds. It should be mentioned that the way I introduce the access of unrestricted households to foreign bond market is my value added to the literature.

At the same time the exogenous part of the term premium in a SOE's case may have very interesting interpretation. It may capture investors' sentiment and risk aversion associated with events exogenous to the domestic economy that shaped the global financial markets. Consider e.g. the effects of the news concerning quantitative easing (QE) tapering in the United States that had an impact on the bond yields of many SOEs (Figure 2). If one interprets

Figure 2: The effects of the QE tapering on the SOE yields



Source: Bloomberg data

In the figure I mark three periods of the "taper talk". They were associated with the following taper remarks:
1) May 22, 2013: Chairman Bernanke tells Congress that the Fed may reduce the size of month bond purchases.
2) June 19, 2013: Chairman Bernanke says the Fed will begin QE taper late 2013 and end it by mid 2014 if economy revives.
3) September 18, 2013: The Fed says the economy is not strong enough, therefore it will carry on QE .
4) November 20, 2013: the FOMC minutes suggest that taper will begin shortly.

these changes in yields as driven mainly by investors' sentiment, analyzing the term premium shock may indicate their macroeconomic consequences.

Therefore, in my model the term premium may capture the impact of both endogenous factors such as the external debt level and exogenous factors[5]. The model consists of 5

[5]This assumption is similar to the approach of general equilibrium business cycle models of sovereign default which allow sovereign spreads to be influenced by both endogenous mechanism and exogenous factors. The former include financing cost of working capital that allows to translate e.g. domestic productivity shocks to sovereign spreads, while the latter may refer to exogenous changes in international interest rate (see Mendoza and Yue (2012), Neumeyer and Perri (2005) and Uribe and Yue (2006)).

types of agents: 2 types of households, firms, the central bank and the government. In the following sections I describe them. After setting the optimization problems of agents I solve and linearize them around the steady state which is a standard procedure for estimated DSGE models (Christiano et al. 2005; Smets and Wouters 2003).

3.1 Households

Households maximize their lifetime utility subject to their budget constraint. They take utility from consumption and leisure whilst exhibiting habit formation in the former. They finance consumption with the income from work and they may allocate their consumption in time by issuing/buying bonds.

After log-linearization I aggregate households' consumption, labor supply and Lagrange multiplier in the same fashion as in Andrés et al. (2004); Kiley (2014); Chen et al. (2012) by assigning weight ω and $1-\omega$ for - respectively - restricted and unrestricted households.

3.1.1 Unrestricted households

Unrestricted households maximize their lifetime utility[6]:

$$E_0 \sum_{t=0}^{\infty} (\beta)^t \zeta_{d,t} \left[\frac{1}{1-\sigma} (C_t^U - \xi C_{t-1}^U)^{1-\sigma} - \frac{1}{1+\rho} (N_t^U)^{1+\rho} \right]$$

subject to the budget constraint:

$$C_t^U + \frac{B_t^U}{P_t R_t} + \frac{Q_t B_t^{U*}}{P_t^* (R_{L^*,t} \Gamma_{F,t})^L} + \frac{B_t^{L,U}}{P_t((1-\zeta_{RL,t})^{-1} R_{L,t})^L} + \frac{\vartheta}{2} [\kappa \frac{Q_t B_t^{U*}}{B_t^{L,U}} - 1]^2 = W_t N_t^U + \frac{B_{t-1}^U}{P_t} + \frac{Q_t B_{t-L}^{U*}}{P_t^*} + \frac{B_{t-L}^{L,U}}{P_t}$$

At any t unrestricted households decide on real consumption C_t^U, labor effort N_t^U and amount of bonds they want to purchase. They receive real wage W_t for every unit of labor. They discount the future with the discounting factor β. Their time preferences are subject to a shock $\zeta_{d,t}$. Q_t denotes the real exchange rate in the domestic economy against the foreign economy, whereas P_t and P_t^* - price indexes - respectively - in the domestic and foreign economies.

Since unrestricted households have access to all asset types in the model, they may be perceived as more sophisticated participants in financial markets. However, as they have

[6] In the model description the convention is as follows: capital letters with time subscript depict variables in their levels, capital letters without time subscript depict steady-state values, whereas small letters with the time index - deviations from the steady state.

to manage their portfolio, they also have to pay some costs associated with it. These costs give rise to two crucial financial frictions in my model since they result in the time-varying term premium. They may be interpreted as transaction costs or costs of acquiring new information. In technical terms these costs together with the household segmentation serve the introduction of imperfect asset substitutability (see e.g. Kiley, 2014). I include two types of costs:

1. proportional transaction cost (see Andrés et al., 2004; Kiley, 2014; Chen et al., 2012) for domestic long term bonds that unrestricted agents have to pay when they buy long-term bonds: $(1-\zeta_{RL,t})^{-1}$, where $\zeta_{RL,t}$ is an exogenous shock. Andrés et al. (2004) point out that this cost corresponds to "exogenous interest differentials" described by Tobin. These differentials are part of the wedge that creates fluctuations in the relative prices of different assets under the assumption that they are not perfect substitutes (Tobin, 1982). In what follows,$\zeta_{RL,t}$ will be described as a "term premium shock".

2. portfolio adjustment cost $\frac{\vartheta}{2}[\kappa\frac{Q_t B_t^{U*}}{B_t^{L,U}}-1]^2$ that is paid when the structure of investor's portfolio deviates from the preferred one, i.e. $\kappa=\frac{B^{L,U}}{QB^{U*}}$. This cost reflects the implication of the preferred habitat theory according to which agents prefer to keep a given structure of assets (see: Culbertson, 1957; Modigliani et al., 1966 for classical articles in this literature and Vayanos and Vila, 2009 for a recent application). Since deviations of asset structure are undesirable for investors, they are associated with the cost in the model.

Unrestricted household optimization problem leads in particular to the following three intertemporal first order conditions (FOCs):

$$\frac{\Lambda_t^U}{P_t R_t}=\frac{\beta E_t\Lambda_{t+1}^U}{E_t P_{t+1}} \tag{3}$$

$$\frac{Q_t\Lambda_t^U}{(R_{L^*,t}\Gamma_{F,t})^L P_t^*}+\frac{\vartheta\kappa}{B_t^{L,U}}[\kappa\frac{Q_t B_t^{U*}}{B_t^{L,U}}-1]=\frac{\beta^L E_t Q_{t+L}\Lambda_{t+L}^U}{E_t P_{t+L}^*} \tag{4}$$

$$\frac{\Lambda_t^U}{((1-\zeta_{RL,t})^{-1}R_{L,t})^L P_t}+\frac{\vartheta\kappa Q_t B_t^{U*}}{(B_t^{L,U})^2}[\kappa\frac{Q_t B_t^{U*}}{B_t^{L,U}}-1]=\frac{\beta^L E_t\Lambda_{t+L}^U}{E_t P_{t+L}} \tag{5}$$

where Λ_t^U is a Lagrange multiplier for unrestricted households (budget constraint shadow price) at time t. Eq. 3 is standard and it depicts the intertemporal choice when these households use one-period bonds to allocate their consumption over time. Eq. 4 and 5 reflect the intertemporal allocation of unrestricted household when they use long term bonds.

Since unrestricted households have access to all three type of bonds, they should be indifferent between them. It implies no arbitrage opportunities and the same real net[7] rate

[7] By net I mean adjusted for the transaction and adjustment costs.

of return from these bonds. This requirement is embodied in equations 3, 4 and 5 by the means of the same shadow price that occurs in all three equations. Exploiting no arbitrage opportunities I derive two crucial equations in the model: the interest rate term structure and the uncovered interest parity (UIP).

Interest rate term structure

$$r_{L,t} = E_t \frac{1}{L} \sum_{i=0}^{i=L-1} r_{t+i} + \iota[q_t + d_t - b_t^{L,U}] + \zeta_{RL,t} \tag{6}$$

where $\zeta_{RL,t} = \rho_{RL}\zeta_{RL,t-1} + \epsilon_{RL,t}$, $d_t = -b_t^{U*}$ is the external debt of the SOE and $\iota = \frac{1}{\beta^L \Lambda^U} \frac{\vartheta}{B^{L,U}}$ is a parameter.

Eq. 6 depicts the interest rate term structure after log-linearization. The domestic long term interest rate is the sum of expected short term interest rates (as the EH would predict) augmented by the adjustment cost associated with deviations of the ratio of long-term bonds from its preferred value $\iota[q_t + d_t - b_t^{L,U}]$ and the transaction cost $\zeta_{RL,t}$ that follows an autoregressive process. The adjustment cost may be interpreted as an endogenous part of the time-varying term premium, while the transaction cost may be viewed as the term premium shock.

Since the parameter ι is positive, an increase in indebtedness in foreign currency ceteris paribus leads to an increase in the long term interest rate. It reflects the intuition that an increase in the foreign-denominated debt of the economy should lead to an increase in government financing costs. In this way I include the impact of the increase in external indebtedness on the term premium. In contrast, an increase in demand for domestic long term bonds leads to their higher price and lower yield (long term interest rate).

Uncovered interest parity

$$r_t - r_t^* = E_t q_{t+1} - (1-\tau) q_t + E_t \pi_{t+1} - E_t \pi_{t+1}^* + \rho_t + \tau[q_t + d_t - b_t^{L,U}] \tag{7}$$

where$\tau = -\frac{1}{\beta^L Q \Lambda^U} \frac{\vartheta}{B^{U*}}$.

Equation 7 presents the UIP. As in the standard UIP any deviations between domestic short-term interest rates and foreign interest rate can be explained by the expected change in the real exchange rate $E_t q_{t+1} - q_t$, expected future inflation differentials between domestic and foreign economy $E_t \pi_{t+1} - E_t \pi_{t+1}^*$ and risk premium that depends on the relative foreign indebtedness of the domestic economy subject to a shock $\zeta_{Q,t}$ (see Schmitt-Grohe and Uribe (2003)):

$$\rho_t = \varrho_Q (d_t + q_t - p_t - gdp_t) + \zeta_{Q,t}$$

The UIP that I obtained includes also a non-standard part: $\tau[q_t + d_t - b_t^{L,U}]$ that results from the financial friction (adjustment costs) faced by unrestricted households. Since parameter τ is positive, the impact of the adjustment cost is qualitatively the same as in the term structure equation (positive if external debt increases; eq. 6). Furthermore, a positive τ implies that an increase in external debt acts similarly to the risk premium shock in the UIP, i.e. a higher external debt is conducive to the domestic exchange rate depreciation and the rise in interest rates. This is also consistent with the interpretation that external debt affects the term premium.

3.1.2 Restricted households

Restricted households are identical to unrestricted household in all aspects but the access to bond markets[8]. They maximize the following lifetime utility:

$$E_0 \sum_{t=0}^{\infty} (\beta)^t \zeta_{d,t} \left[\frac{1}{1-\sigma} (C_t^R - \xi C_{t-1}^R)^{1-\sigma} - \frac{1}{1+\rho} (N_t^R)^{1+\rho} \right]$$

subject to the budget constraint:

$$C_t^R + \frac{B_t^{L,R}}{P_t (R_{L,t})^L} = W_t N_t^R + \frac{B_{t-L}^{L,R}}{P_t} - T_t$$

Restricted households decide on real consumption C_t^R, labor effort N_t^R and the amount of long term bonds they want to trade. They receive real wage W_t that is equal to the real wage obtained by unrestricted households[9]. They discount the future with the factor β while time preferences are subject to a shock $\zeta_{d,t}$ (the same as for unrestricted households).

Restricted households have access only to domestic long-term bonds so they may be perceived as unsophisticated savers. Their transactions in the bond market are not associated with any costs as they do not have to manage their portfolios. This feature of the model implies bond market segmentation.

3.2 Firms

Production is modeled as a three-stage process in order to capture price stickiness as well as monopolistic competition in the goods market in three sectors: export, import and domestic production. In the first stage production firms produce homogeneous goods in a perfectly competitive market. In the second stage domestic, exporting and importing retailers mark

[8]Furthermore, restricted households - contrary to unrestricted ones - have to pay lump-sum tax, but this difference has no impact on the model after its log-linearization.

[9]This is a simplifying assumption. Instead of it I could assume that the wages of restricted and unrestricted households change proportionally allowing for their different levels.

these goods and sell them to aggregators charging a mark-up. They set prices according to the Calvo scheme, in which a portion of retailers can set the optimal price, while the remaining group indexes its price to the current and the steady state inflation rates. As retailers act under monopolistic competition they maximize their profit taking aggregators demand function as given. Finally, aggregators combine heterogeneous goods bought from domestic and importing retailers into a homogeneous final consumption goods.

3.2.1 Production firms

I assume a simple one-factor production function for a firm that produces the homogeneous good (see e.g. Andrés et al. 2004):

$$Y_t^p = Z_t N_t$$

where Y_t^p is the output of the production firm, N_t is labor supply and $z_t = \log Z_t$ measures productivity following an $AR(1)$ process and is subject to a productivity shock $\zeta_{z,t}$. Looking at the supply side of the economy, since labor is the only production factor, changes in the households labor supply constitute the only endogenous mechanism that drives output. I do not include capital into the production function leaving the interrelationship between the long-term rate and investments for further research.

Since production firms act in a perfectly competitive market the real price of goods they sell equals the real marginal cost of production:

$$MC_t = \frac{W_t}{Z_t}$$

where MC_t stands for real marginal cost and W_t is a real wage.

3.2.2 Aggregators

Aggregators buy input from domestic and importing retailers to produce final goods:

$$Y_t^{\frac{1}{1+\mu}} = \left[\eta^{\frac{\mu}{1+\mu}} (Y_t^h)^{\frac{1}{1+\mu}} + (1-\eta)^{\frac{\mu}{1+\mu}} (Y_t^f)^{\frac{1}{1+\mu}}\right]$$

where Y_t is a final good, Y_t^h is an output of domestic retailers, Y_t^f is an output of importing retailers, μ is a parameter in the Dixit-Stiglitz aggregator and η is a home bias parameter. Y_t^h and Y_t^f aggregate the output of individual retailers according to the following formulas:

$$(Y_t^h)^{\frac{1}{1+\mu_h}} = \int_0^1 Y_t^h(j_h)^{\frac{1}{1+\mu_h}} dj_h \quad (Y_t^f)^{\frac{1}{1+\mu_f}} = \int_0^1 Y_t^f(j_f)^{\frac{1}{1+\mu_f}} dj_f$$

where μ_h is a steady-state mark-up of the domestic retailer over marginal cost and μ_f is a steady-state mark-up of the importing retailer over the foreign price.

Since aggregators act in perfectly competitive market, prices are aggregated according to the following formula:

$$P_t^{\frac{1}{1+\mu}} = \left[\eta^{\frac{\mu}{1+\mu}}(P_t^h)^{\frac{1}{1+\mu}} + (1-\eta)^{\frac{\mu}{1+\mu}}(P_t^f)^{\frac{1}{1+\mu}}\right]$$

where domestic and imported prices are given by:

$$(P_t^h)^{\frac{-1}{\mu_h}} = \int_0^1 P_t^h(j_h)^{\frac{-1}{\mu_h}} dj_h \quad (P_t^f)^{\frac{-1}{\mu_f}} = \int_0^1 P_t^f(j_f)^{\frac{-1}{\mu_f}} dj_f$$

Aggregators equalize marginal revenue with marginal cost for the following profit function:

$$Y_t P_t - Y_t^h P_t^h - Y_t^f P_t^f$$

subject to above described aggregation functions. This maximization gives the following demands for goods:

$$Y_t^h = \eta(\frac{P_t^h}{P_t})^{-\frac{1+\mu}{\mu}} Y_t \quad Y_t^f = (1-\eta)(\frac{P_t^f}{P_t})^{-\frac{1+\mu}{\mu}} Y_t$$

3.2.3 Retailers

There are three types of retailers in the model: domestic, exporting and importing. In this subsection I present only the maximization problem of domestic retailers since the problems of exporting and importing retailers are analogous.

There is a continuum of domestic retailers indexed $j \in [0;1]$ who purchase from production firms homogeneous goods Y_t^p at the nominal price $P_{p,t} = P_t MC_t$. A retailer, in turn, brands these goods at no cost and sell them as $Y_t^h(j)$ at the price $P_t^h(j)$. She can set the price of her goods as $P_t^{h,opt}(j)$ with the Calvo probability (see Calvo 1983) that equals to $1-\theta_h$ (θ_h is the Calvo parameter of price stickiness). If she does not set her price in the optimal way, she indexes it according to the following formula:

$$P_{t+k}^h(j) = P_{t+k-1}^h(j)\Pi_{t+k-1}^{h,\zeta}$$

where

$$\Pi_{t+k-1}^{h,\zeta} = (1-\zeta^h) + \zeta^h \Pi_{t+k-1}$$

The optimal price set by the retailer is derived from solving the following maximization problem:

$$\max_{P_t^{h,opt}(j)} E_t \sum_{k=0}^{\infty} \beta^k \theta_h^k \left\{ \lambda_{t,t+k} Y_{t+k}^h(j) (\Pi_{k,t+k-1}^{h,\zeta} P_t^{h,opt}(j) - P_{t+k} MC_{t+k}) \right\}$$

subject to the demand of final domestic good producers:

$$Y_{t+k}^h(j) = (\frac{\Pi_{k,t+k-1}^{h,\zeta} P_t^{h,opt}(j)}{P_{t+k}^h})^{-\frac{1+\mu_h}{\mu_h}} Y_{t+k}^h$$

where $\Pi_{k,t+k-1}^{h,\zeta} = \Pi_k^{h,\zeta} \Pi_{k+1}^{h,\zeta} \Pi_{k+2}^{h,\zeta} \cdot ... \cdot \Pi_{t+k-1}^{h,\zeta}$.Finally, after log-linearization I obtain the recursive equation for the optimal price:

$$p_t^{h,opt} = (1 - \beta\theta_h)(mc_t + \pi_{t-1} - \pi_{t-1}^{h,\zeta}) + \beta\theta_h E_t(p_{t+1}^{h,opt})$$

Since $1 - \theta_h$ retailers reset their prices and θ_h index them, the aggregate price of domestic retailers is given by:

$$p_t^h = \theta_h(p_{t-1}^h + \pi_{t-1}^{h,\zeta} - \pi_{t-1}) + (1 - \theta_h) p_t^{h,opt}$$

3.3 The closure of the model

The central bank is assumed to conduct monetary policy according to the standard Taylor rule (see Taylor 1993), i.e. it sets domestic short-term interest rates in the following form:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\gamma_R} \left(\left(\frac{\pi_t}{\pi}\right)^{\gamma_\pi} \left(\frac{y_t}{Y}\right)^{\gamma_y}\right)^{(1-\gamma_R)} \exp\{\zeta_{R,t}\}$$

where $\zeta_{R,t}$ is a monetary policy shock and γ's are monetary policy parameters.

In the model government is assumed not to deviate from the steady-state, which implies: $g_t = 0$, $b_{L,t} = 0$ and $t_t = 0$. I leave the interrelationship between fiscal policy and long term interest rates for further research. Similarly to the role of investments, this is beyond the scope of this paper since it requires some additional a priori assumptions e.g. on how the government spending reacts to financing costs or what is an appropriate fiscal policy rule. I do not pretend to take position on these issues in this paper.

GDP consists of consumption, government expenditure and net exports:

$$GDP_t = C_t + G_t + Q_t \tilde{P_t^{h*}} Y_t^{h*} - \tilde{P_t^f} Y_t^f$$

3.4 Balance of payments

The balance of payments takes the following form (in domestic currency after log-linearization):

$$\tilde{P}_t^f Y_t^f + Q_t R_{t-1}^* D_{t-1} = Q_t \tilde{P}_t^{h*} Y_t^{h*} + Q_t D_t$$

This formulation of balance of payments depicts that capital outflows (purchases of imported goods and debt repayments) must equal capital inflows (exports and a newly issued debt D_t).

4 Data, Calibration and Estimation

I partly calibrate and partly estimate the parameters of the model depicted in section 3. This is a common procedure that serves bringing a DSGE model to the data (see e.g. Christiano et al. 2005, Gali and Monacelli 2005 and Smets and Wouters 2003). Parameters that are well-established in the literature, steady state ratios, or those that may be derived from the steady state are calibrated. Other parameters are estimated.

4.1 Data

I choose a data set that allows me to reliably estimate the impact of the long term interest rate on the business cycle in Poland. Firstly, I include the real GDP index and the inflation rate (as measured by the HICP) in Poland as they are the main variables that characterize the business cycle. Secondly, the data set covers the long term interest rate in Poland, i.e. the 10-year swap rate[10], because I aim at estimating its impact on the business cycle in Poland. I also include the short term interest rate (represented by WIBOR 3M) since it is the monetary policy instrument and I am interested in the interactions between the long term rate and monetary policy [11]. Thirdly, I add the real consumption index and the REER in Poland in order to capture crucial channels through which the long term interest rate impacts GDP and inflation: consumption allocation (through Euler equation) and exchange rate formation (via the UIP). I append the data on Polish economy with 3 variables describing the euro area: real GDP, HICP and the short term interest rate (EURIBOR 3M). I use them so as to reliably estimate the impact of the foreign economy on the Polish exchange rate and price formation. All in all, I include 9 data series, out of which six characterize the Polish economy and three the euro area. My estimation includes 44 quarterly observations from 1q2004-4q2014. I choose not to include earlier observations as there were at least two important structural

[10] In the baseline model I take the swap rate instead of a government bond yield in order to abstract from government credit risk and to concentrate on the pure term premium. The maturity choice is motivated by the popularity of 10-year bonds in financial markets as the most liquid assets that are also taken into account in international comparisons (e.g. Maastricht long term interest criterion is based on the 10-year yield). As a robustness check I test also government bond yield as well as 4 - year swap rate and I find similar results to my baseline estimation.

[11] Although WIBOR 3M is not a monetary policy instrument, it is well-controlled by the NBP monetary policy instruments (Łyziak, Kapuściński, Stanisławska, Przystupa, Wróbel and Sznajderska 2014).

changes in the Polish economy in 1q2004: 1. the Polish central bank introduced a constant inflation target after several years of varying targets due to the disinflation process; 2. Poland entered the European Union which strongly impacted the perspectives of both Polish firms and households.

The model is estimated as a linear system of equations in which variables are in the form of logarithmic deviations from the steady state. Such model specification implies that the time series used in the estimation should be stationary. Since some macroeconomic variables in my sample are influenced by long-run growth trend (GDP, consumption) they are made stationary by removing the HP trend from their natural logarithms. I also remove the trend from the REER since, at least in theory, the REER of a converging economy may tend to appreciate.

Inflation rates and interest rates are believed to be stationary[12], thus they are demeaned. Hence, I implicitly assume that the recent global financial crisis and recession in the euro zone have not influenced the steady state for inflation and interest rates in both Poland and the euro area. In case of Poland a relatively good economic performance during the recent crisis supports this approach. In the euro area, in turn, I assume that the economic slump after the global financial crisis has been temporary and both inflation and interest rate will come back to previous levels.

The data set is taken from the Eurostat, with the exception of the long-term interest rate that is obtained from Bloomberg.

4.2 Calibrated parameters

I present calibrated parameters in Table 5. The quarterly discount rate is set to $\beta = 0.99$ which matches the annual real interest rate of 4% that is a common value in the literature. The parameter in the final goods producer aggregator is calibrated to $\mu = 2$ so that the elasticity of substitution between domestic and foreign goods (Armington elasticity) given by $\frac{\mu+1}{\mu}$ equals 1.5 (Gradzewicz et al. 2006, see also Ruhl 2008 and Feenstra et al. 2014 for a discussion of micro and macro Armington elasticities). The parameter in the exporters demand function is calibrated to $\mu^* = 1$ in order to match export elasticity found in Imbs and Mejean (2010). The home bias parameter η and import-to-GDP ratio $\frac{Y^f}{GDP}$ is set consistently with the ratio of exports to absorption observed in the Polish data accounting for the import intensity of exports (Bussiére et al. 2013). Debt share to GDP, $\frac{D}{GDP}$, is calibrated in line with the average Polish net international position and together with the import-to-GDP ratio it determines the steady-state value of net exports and consumption to GDP. The elasticity

[12]Formal tests suggest that these variables may have a unit root. However, due to my relatively short sample (44 observations) I rely more on economic intuition as far as the stationarity of the inflation and interest rates is concerned.

Table 5: Selected calibrated parameters

Parameter	Value	Parameter	Value
β	0.99	$\frac{D}{GDP}$	2.28
μ	1.00	$\frac{Y^f}{GDP}$	0.28
μ^*	1.00	R^*	1.0047
η	0.7	ϱ_Q	0.0048

of risk premium to debt-to-GDP ratio ϱ_Q is derived from the averages of the interest and inflation rates in Poland and in the euro area.

4.3 Estimated parameters and estimated shocks

I estimate the log-linearized approximation of the model around the steady state using Bayesian inference. Table 6 presents the prior and posterior values of estimated parameters. As it is a common practice in the literature I set prior assumptions such that they are relatively uninformative and in line with the existing studies taking a special account for applications for Poland (see e.g. Brzoza-Brzezina et al. 2014; Grabek et al. 2007). I run a standard estimation procedure using the Metropolis-Hastings algorithm with 2 chains (500 000 draws each) out of which I burn the first half of each. I implement Brooks and Gelman (1998) diagnostic tests in order to confirm the stability and convergence of the parameter values.

I find a relatively strong external habit formation of consumption in Poland (i.e. high ξ). Since I include consumption as an observable variable in my estimation, this result should not come as a surprise. It is attributable to the relatively stable consumption pattern in Poland observed since the financial crisis. The intertemporal substitution for labor σ_n and consumption σ_c are similar to those obtained in the earlier studies which is a desired feature of my results as it suggests that the utility function of households is relatively stable over time. Furthermore, I find a relatively strong domestic price stickiness (high Calvo parameters) in the data which reflects strong inflation persistence. The estimated Calvo parameters are in line with the micro study for Poland (Macias and Makarski 2013).

According to my estimation the parameters in the monetary policy rule, ϕ's, turn out to be higher than previously assessed. It may be attributable to a change in policy reaction function associated with different time horizons of estimations that cover different terms of the Monetary Policy Councils in Poland.

Priors for the standard deviations of the parameters were mainly set to 0.1 as it is usually assumed (Christoffel et al. 2008; Adolfson et al. 2005). A few exceptions to this pattern were related to the different degree of the uncertainty about parameter values in my prior

Table 6: Selected estimated parameters

	Prior			Posterior	
	type	mean	std dev.	mode	std dev.
ξ	beta	0.5	0.1	0.72	0.06
σ_c	norm	1.7	0.3	1.86	0.27
σ_n	norm	1.7	0.3	1.71	0.29
ι	invg	0.1	0.2	0.02	0.003
τ	invg	0.1	0.2	0.19	0.04
ω	norm	0.5	0.2	0.44	0.20
θ_h	beta	0.7	0.1	0.78	0.04
θ_f	beta	0.7	0.1	0.75	0.07
$\theta_h^\star$	beta	0.7	0.1	0.81	0.07
ζ_h	beta	0.5	0.1	0.40	0.10
ζ_f	beta	0.5	0.1	0.46	0.10
$\zeta_h^\star$	beta	0.5	0.1	0.50	0.10
ϕ_R	norm	0.7	0.4	0.92	0.02
ϕ_π	norm	2.0	0.4	2.17	0.36
ϕ_y	norm	0.5	0.4	0.61	0.28

knowledge. Nevertheless, these values are also relatively uninformative and close to these in literature (Smets and Wouters 2003).

Posterior standard deviations were estimated to be close to or smaller than prior assumptions. The parameters about which the data seems to be relatively uninformative include the price indexation parameters: ζ_h, ζ_f and $\zeta_h^\star$. A possible explanation for this phenomenon is that, amidst strong price stickiness, it is difficult to identify the indexation pattern of a tiny share of importing and exporting retailers that optimize their prices.

As far as shock processes are concerned I set prior autoregression coefficients equal to 0.7 with standard deviations of 0.1 while the prior means of standard deviations are set to 0.01 (Table 7). Since the estimates of shock processes are uninterpretable on their own I present the variance decomposition of main variables in Table 8. It reveals that in the long run the term premium shock has a negligible impact on GDP and inflation volatilities. At the same time this shock was the main driver of the long term interest rate. Hence, exogenous factors that drove long term rates in Poland did not have a significant impact on GDP and inflation volatilies.

Referring to other sources of GDP volatility, the role of the foreign shocks should be stressed. Their strong impact reflects the influence of foreign economy, and demand in particular, on the Polish economy. Furthermore, supply factors seem to have played an important role in determining Polish GDP which is reflected in significant share of the productivity shock in GDP variance decomposition. The risk premium and the export preferences shocks,

Table 7: Selected estimated parameters of structural shocks

	Prior			Posterior	
	type	mean	std dev.	mode	std dev.
ρ_D	beta	0.7	0.1	0.79	0.050
ρ_z	beta	0.7	0.1	0.71	0.088
ρ_ρ	beta	0.7	0.1	0.86	0.046
ρ_{ex}	beta	0.7	0.1	0.87	0.039
ρ_{RL}	beta	0.7	0.05	0.76	0.071
ς_D	invg	0.01	inf	0.005	0.001
ς_z	invg	0.01	inf	0.016	0.006
ς_ρ	invg	0.01	inf	0.003	0.0005
ς_{ex}	invg	0.01	inf	0.041	0.005
ς_R	invg	0.01	inf	0.001	0.0002
ς_{RL}	invg	0.01	inf	0.002	0.0002

Table 8: Variance decomposition

Shock type/ share in variance	GDP	π	c	r	$tp*$	q
Time preference	7.74	11.46	37.19	26.15	0.65	0.20
Productivity	25.68	58.17	23.17	27.40	0.23	0.55
Risk premium	14.89	1.00	3.05	4.20	1.54	6.78
Export preferences	5.65	6.72	8.65	8.23	12.65	87.00
Monetary policy	15.40	13.84	9.83	15.94	0.36	3.60
Term premium	0.16	0.22	0.75	0.46	84.08	0.00
Foreign	30.49	8.59	17.37	17.63	0.60	1.86

*) the term premium i.e. the difference between long term interest rates and the expected path of short term interest rates.

in turn, impact GDP by driving exchange rate fluctuations were also the important determinants of GDP volatility in the SOE (Brzoza-Brzezina et al. 2014). Furthermore, there is also a substantial role of monetary policy and time preference shocks in driving GDP volatility that seems to result from the impact of these shocks on consumption volatility.

As far as inflation variance is concerned, it is heavily affected by the productivity shock. Since it is the only supply shock in the model, this result indicates that prices in the SOE may be strongly affected not only by shifts in productivity, but also by such supply factors as commodity and energy prices or VAT changes.

4.4 The empirical importance of the term premium

The very moderate impact of the term premium shock on GDP and inflation volatilities may suggest a limited role played by the term premium in the SOE. Such conclusion may not be correct, however, since in my model the term premium consists not only of the exogenous part but it also includes an endogenous part. Therefore, in order to verify whether the term premium and the way I model it are supported by the data, I construct a model in which I replace the endogenous mechanism described in section 3 with a simple exogenous autoregressive process. Thus, the alternative model represents an agnostic way of including the deviations from the EH in which it is assumed that the term premium exists and it is impossible to explain it with any interpretable economic mechanism.

In particular, in the alternative model eq. 6 and 7 are replaced with equations - respectively - 8 and 9:

$$r_{L,t} = E_t \frac{1}{L} \sum_{i=0}^{i=L-1} r_{t+i} + \zeta_{RL,t} \tag{8}$$

$$r_t - r_t^* = E_t q_{t+1} - q_t + E_t \pi_{t+1} - E_t \pi_{t+1}^* + \rho_t \tag{9}$$

where

$$\zeta_{RL,t} = \rho_{RL} \zeta_{RL,t-1} + \epsilon_{RL,t}$$

and ϵ_{RL} are iid innovations.

I estimate the alternative model with the same data set as my baseline model. In order to assess the data fit of two models estimated with Bayesian inference I compare their marginal data densities (MDD) that are the likelihood functions integrated over the model parameters. This is a standard procedure (see An and Schorfheide 2007). It turns out that the baseline model explains the data much better than the alternative model. Log MDD in my model amounts to 1538.7 while in the alternative model it equals 1525.9. Assuming that a priori I do not prefer one model over another, it implies a very strong evidence in favor of my model as measured by the Bayes factor that equals $\exp\{1538.7 - 1525.9\} = \exp\{12.8\}$. This conclusion is based on thresholds for models comparison from Kass and Raftery (1995). Thus, if one attempts to include the term premium into DSGE SOE model, one should prefer my specification to the one in which the term premium is completely exogenous.

4.5 Estimation robustness checks

Having shown that the way I model the endogenous mechanism in the term premium helps in explaining the data, I move to an assessment whether my estimation results depend on

Figure 3: Term premium in empirical and DSGE models

potentially important modeling choices I make. I divide these decisions into two categories: choices on observables and priors for the estimated parameters. In order to check whether my results are robust I repeat my estimation changing one of these assumptions.

Firstly, I substitute the 10-year swap rate with the term premium estimated by me from the empirical yield curve model of Adrian et al. (2013) for the Polish yield curve (see section 1). I use this alternative observable in order to check whether the importance of the term premium for GDP and inflation depends on how my model estimates the term premium. As figure 3 suggests, the empirical term premium and the one from my estimation in general seem to comove, though they noticeably differ from each other.

The inclusion of the empirical term premium has little impact on the estimation results. A vast majority of estimated parameters do not change, with the noticeable exception of an increase in variance of long-term interest shock $\zeta_{RL,t}$ and a decrease in the share of restricted households ω. This change is associated with the fact that the term premium in the alternative model turns out to be explained only by the long term interest rate shock. It means that the model was not able to interpret developments in the empirical term premium by means of other shocks and endogenous mechanisms. At the same time, however, the estimated impact of the term premium shock on macroeconomic variables remains very moderate (close to zero in case of impact on GDP and inflation) which is also reflected in parameter ω estimated to be close to zero.

Secondly, I use a 4-year swap rate and a 10-year government bond yield as an observable long term interest rate instead of the 10-year swap rate. I use the former in order to check whether the maturity of the long term interest rate matters for the results. In case of the latter I verify whether it is important to take as an observable the interest rate that does not account for the government credit risk. According to these alternative estimations neither change makes a significant difference for the results.

Finally, I change prior assumptions for the following parameters: ι, τ, ω setting them at 0.01. Furthermore, I set priors for parameters: σ_c, σ_n at 2. In order to check robustness of above-mentioned parameters I conduct five estimations, one for each parameter change. Neither of these estimations results in a substantially different IRFs or variance decompositions as compared with the baseline estimation, though changes in priors affect posterior values of manipulated parameters.

5 The role of the term premium

In this section I discuss the significance of the term premium in the estimated model by analyzing both term premium shock and the role of the endogenous mechanism in the term premium.

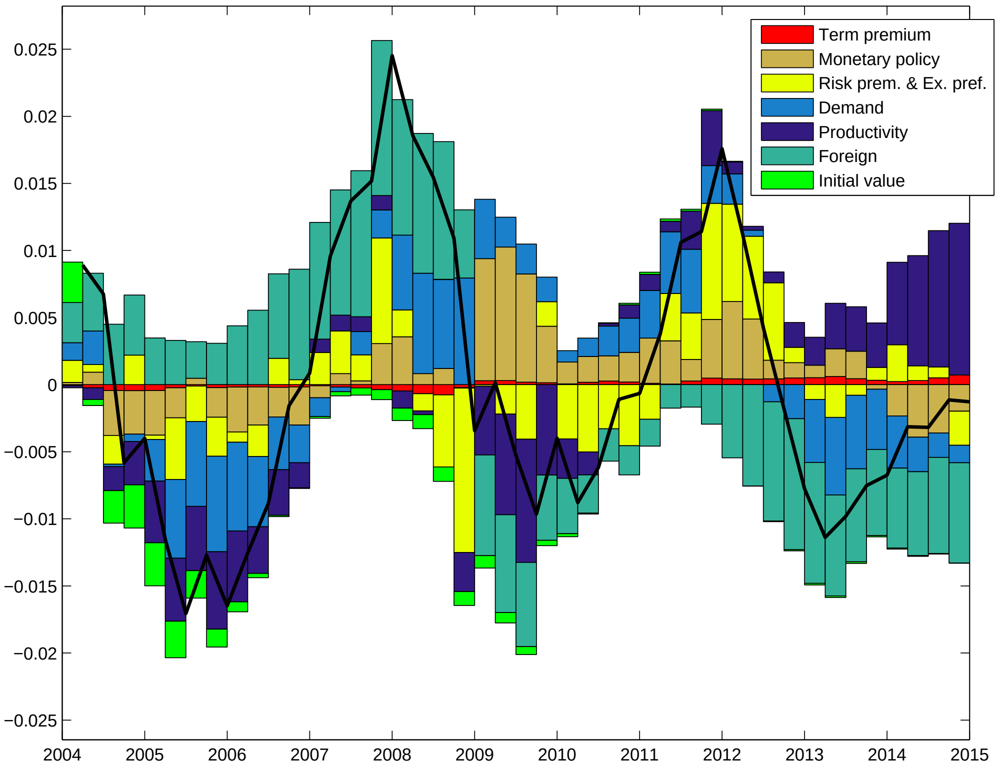
5.1 The term premium shock: historical decompositions and IRFs

Historically, the term premium had a very moderate impact on GDP volatility in Poland (Figure 4). In 2013 its impact was slightly positive and the term premium shock moderated the fall in economic activity. On the other hand, in 2007-2008, i.e. just before the financial crisis, the term premium shock was conducive to lowering the still positive output gap. Thus, in both periods the term premium shock was countercyclical.

As far as the impact on inflation is concerned, it was very similar to that observed for GDP. The term premium shock lowered inflation before 2009 and increased it in 2014. However, the magnitude of this influence was even lower than that for GDP.

The term premium shock was historically the main driver of the term premium (Figure 6). To some extent this impact may be mapped to important macroeconomic events. For instance, positive values of the term premium shock just before and during the outbreak of the global financial crisis may be associated with the unfavorable investor sentiment in 2008 that led to higher long term interest rates than would be justified by expected short term interest rates and the external debt of the Polish economy. Furthermore, the negative term premium shock in 2014 might have been caused by an increased global liquidity and investors' risk appetite associated with the QE programs conducted by the major central banks.

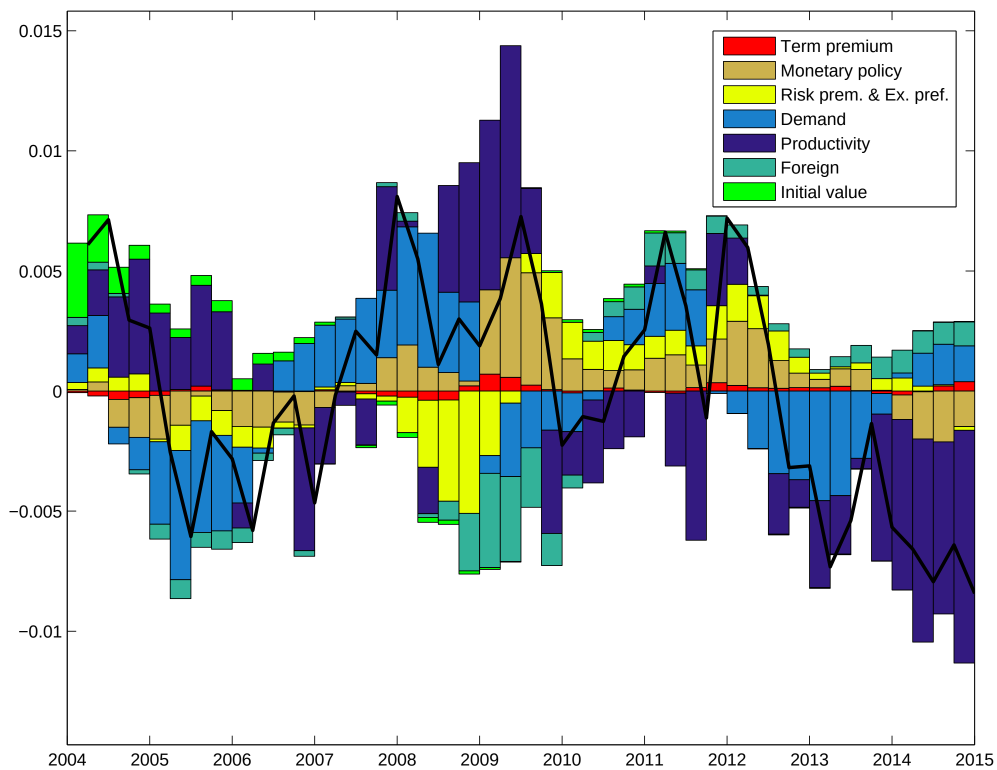
Figure 4: Historical shock decomposition: GDP



In order to understand how the term premium shock affects GDP and inflation I analyze IRFs to this shock (Figure 7). The exogenously driven increase in the term premium (by 0.2 pp.) leads to an increase in the long term interest rate (of the same magnitude) that acts contractionary decreasing consumption (by 0.04%), GDP (by 0.03%) and the inflation rate (by 0.02 pp.). Since consumption decreases, so do imports leading to improved net exports (max. by 0.02 pp.). On the other hand, as the term premium increases driven by exogenous shock, investors want to decrease the value of the external long term debt expressed in the domestic currency. This causes foreign debt to drop which is in line with the positive trade balance. At the same a decrease in the foreign debt induces the exchange rate to appreciate. Responding to these developments, the central bank decreases its short term interest rate, however, its reaction is too weak to mitigate the decline in GDP . On the supply side, the drop in output is driven by a lowered labor supply associated with the decrease in consumption.

Thus, the term premium shock lowers GDP and inflation mainly by decreasing consumption. Indeed, Figure 8 shows that the term premium shock had a noticeable, but very

Figure 5: Historical shock decomposition: inflation



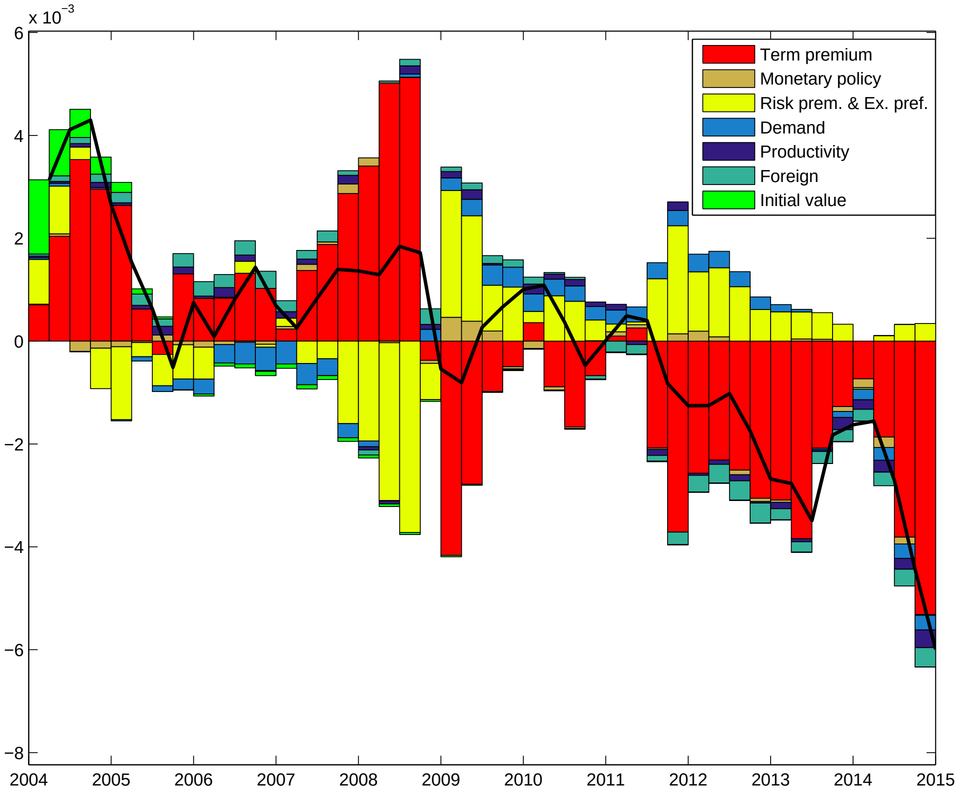
moderate in magnitude, impact on consumption in Poland increasing it in 2009-2014 and decreasing, in particular, before the global financial crisis.

The small impact of the term premium shock on GDP and consumption also influences how long-term interest rates translate into GDP changes. According to the estimation results, the 10-year interest rate has to decrease by 0.58% in order to cause the same cumulated GDP increase over 3 years as a drop in short term interest rates by 0.11%. This means that the NBP short-term interest rate has a 5.1-folds stronger impact on the output gap[13] in Poland than the 10-year long term interest rate (Figure 9). I obtain this result by simulating the long term interest rate shock under the assumption that short-term interest rates are kept at zero by the central bank[14]. Such simulation reflects the situation in which the long-term interest rate changes due to external factors, however the central bank does not respond to economic developments even though, economic agents expect it to do so. I concentrate on

[13]Output gap is defined as GDP deviations from its steady-state.

[14]Technically, I assume that interest rates are set to zero at every period even though the Taylor rule is not switched off. As a consequence, economic agents expect the central bank to behave according to the Taylor rule, however, the latter unexpectedly sets its interest rates to zero.

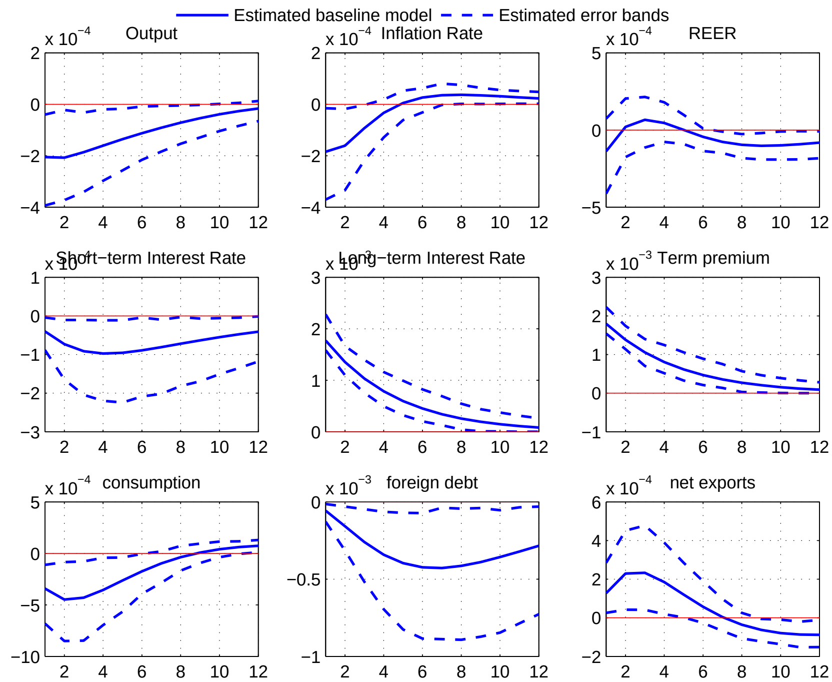
Figure 6: Historical shock decomposition: the term premium



this scenario because it reflects the situation in which the long-term interest rate works as a substitute for the monetary policy and the strength of the central bank reaction to economic developments does not affect the impact of the long-term interest rate. One may think also of other scenarios e.g. the central bank reacts endogenously to developments in the economy (then the impact of long term interest rates on the economy would be much smaller, c.a. 40-fold weaker than short-term interest rates) or the central bank does not react to these developments at all and other agents take this behavior into account (then the model solution would be unstable).

To sum up, the term premium shock has been historically countercyclical. I identify two time periods in which the impact of this shock on GDP and inflation was particularly interesting: before and during the outbreak of the global financial crisis when the term premium shock acted contractionary and in 2013-2014 when it was slightly expansionary. Although the term premium shock affected the Polish economy in an intuitive way during these episodes, the magnitude of this impact was very moderate. However, it does not imply that the term premium as such is of little importance as it consists also of the endogenous

Figure 7: Impulse response functions to a term premium shock



part. I elaborate on this issue in section 5.2.

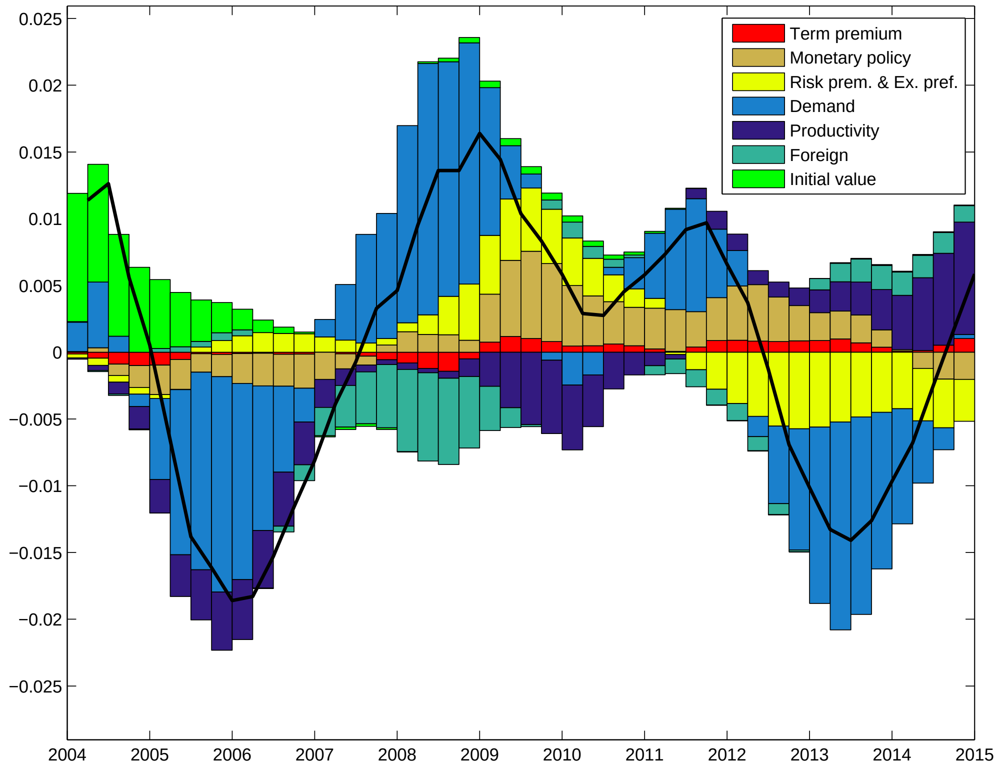
5.2 The term premium: the endogenous mechanism

In order to analyze the role of the endogenous part of the term premium I construct a benchmark model of the SOE in which I switch off the frictions that gives rise to the endogenous and exogenous parts of the term premium which I interpret as removing the term premium itself[15]. Hence, in the benchmark model the budget constraint of unrestricted households is modified. Specifically, there are no transaction and adjustment costs that gave rise to the term premium[16]. I compare my baseline (estimated) model with the benchmark looking at the volatility of main variables and model dynamics (represented by IRFs). Next, I perform a counterfactual simulation in order to analyze what my model and its estimation imply for the role of the term premium for main macroeconomic aggregates in the past. Due to

[15]Formally, the friction that leads to the endogenous part of the term premium (adjustment costs in unrestricted households budget constraint) is not the same as the endogenous part of the term premium. However, assumption that the endogenous part of the term premium is equal zero, i.e. $\iota[q_t + d_t - b_t^{L,U}] = 0$ implies that the additional term that results from the adjustment cost in the UIP equation is also equal zero, i.e. $\tau[q_t + d_t - b_t^{L,U}] = 0$. Thus, as a simplification I describe switching off the financial frictions in households budget constraint as removing the term premium.

[16]Note that the benchmark model is not a newly estimated model of the small open economy. Instead, parameter values are taken from my model that includes also the term premium. In principle, as parameters in both models are believed to be structural, they should be robust to a model specification. In practice, however, they might differ.

Figure 8: Historical shock decomposition: consumption



the presence of the endogenous part in the term premium, these simulations constitute a much more appropriate tool for analyzing the historical importance of the term premium than historical shock decomposition described previously. Finally, I discuss the empirical importance of the results and my contribution to literature.

5.2.1 The comparison of economic dynamics

Intuitively, switching off one shock in the DSGE model should lead to a lower volatility of endogenous variables as the number of disturbances decreases. However, since apart from removing one shock I also switch off the endogenous mechanism, this modification may increase variables' volatility. Indeed the volatility of GDP is significantly higher in the benchmark model (Table 9). On the other hand, the real exchange rate and the long term interest rate volatilities are lower in the benchmark model which means that the term premium stabilizes the economy at the cost of destabilizing the real exchange rate and the long term interest rate.

In order to understand how the term premium influences the model dynamics I analyze

Figure 9: Interest rate and term premium shock that lead to equal cumulative impact on output

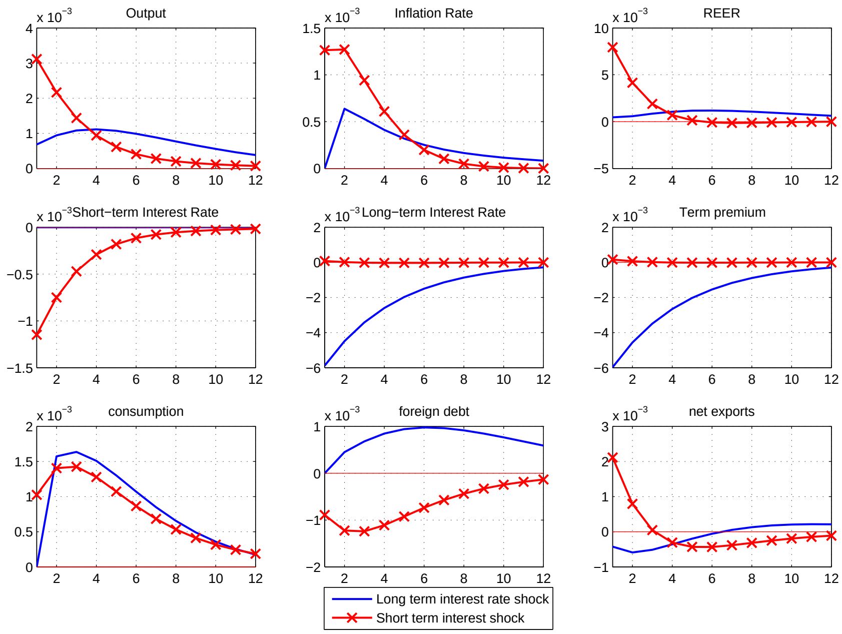


Table 9: Standard deviations of the main variables

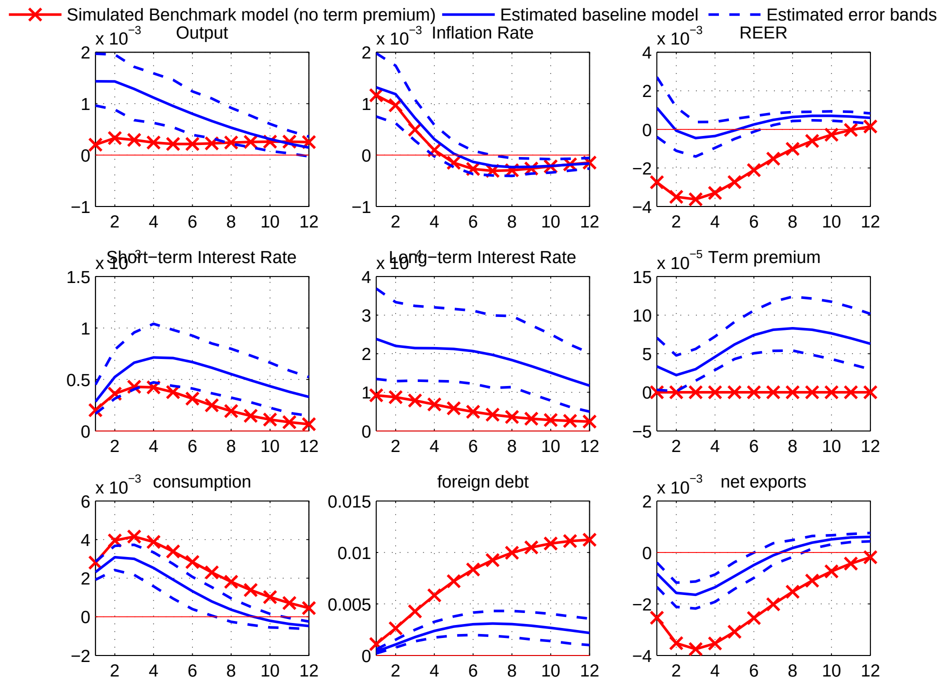
[percentage points]	GDP	c	π	r	r_L	q
Baseline simulation (estimated model)	1.1	1.0	0.6	0.4	0.3	5.0
Benchmark simulation	1.5	1.6	0.6	0.4	0.1	3.4

IRFs in my model and compare them with IRFs in the benchmark model. I concentrate only on time preference, risk premium and export preference shocks since the time-varying term premium has a very weak effect on economic dynamics in cases of productivity and monetary policy shocks.

5.2.2 Time preference shock

Figure 10 presents IRFs for a time preference shock in both models. This is a standard demand shock that makes households more or less impatient. In the case of the increased households' impatience, they prefer to immediately increase their consumption. Since prices are sticky, firms are not able to fully adjust their prices. As a consequence the prices rise by less than they would if they were flexible which leads to an increase in consumption. The demand for imported goods also increases as the consumption of domestic and foreign goods are complementaries. The rise in imports results in a negative trade balance. As the consumption share in GDP is much higher than that of net exports, the net effect of the

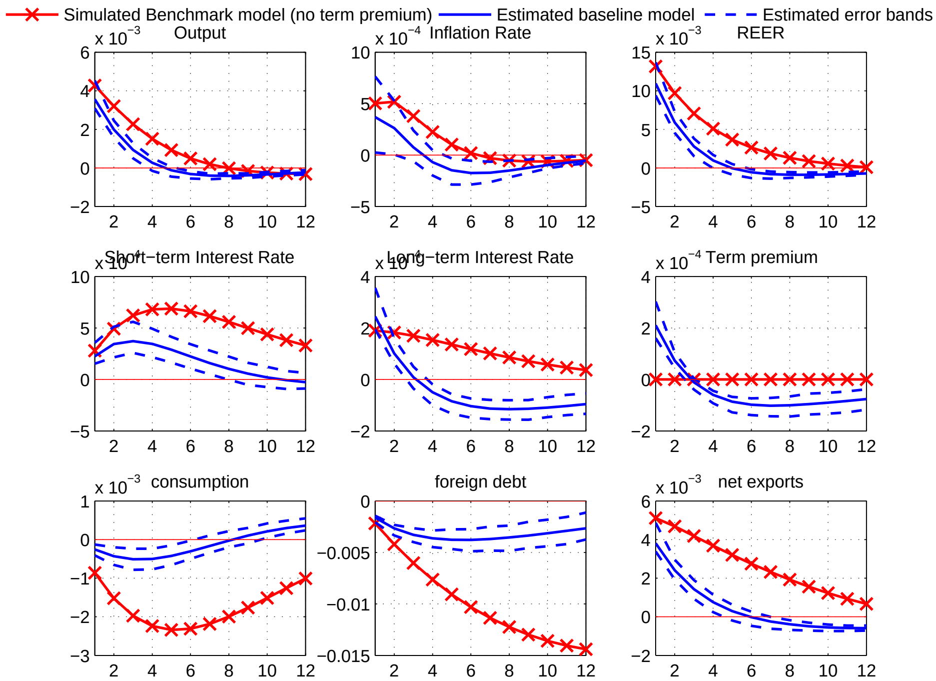
Figure 10: Impulse response functions to a time preference shock



increase in the former and decrease in the latter on GDP is positive.

The comparison of the IRFs from the baseline (estimated) model and the benchmark model (without the time-varying term premium) reveals two main differences in the model dynamics. Firstly, GDP increase is much more pronounced in the estimated model (that contains the term premium). Secondly, the exchange rate in the baseline model depreciates (q rises), while in the benchmark simulation it appreciates (q decreases). These differences may be explained by the impact of the term premium. As it has been already discussed in both models net exports decrease which causes a rise in external debt. Higher external debt implies an increase in the term premium reflected in the rise in the long term interest rate. Higher long term rate acts contractionary (through the Euler equation) and lowers the path of consumption as compared with the model without the term premium. Lower consumption, in turn, leads to a smaller rise in imports. Furthermore, the rise in external debt causes the exchange rate to depreciate which supports exports. Higher exports and lower imports result in much lower trade deficit that is reflected in smaller increase in external debt. The net impact of the time-varying term premium on GDP is positive since higher net exports outweigh lower consumption. At the same time the impact on inflation is statistically insignificant. As a consequence monetary policy that follows the Taylor rule is more restrictive in my model.

Figure 11: Impulse response functions to a risk premium shock

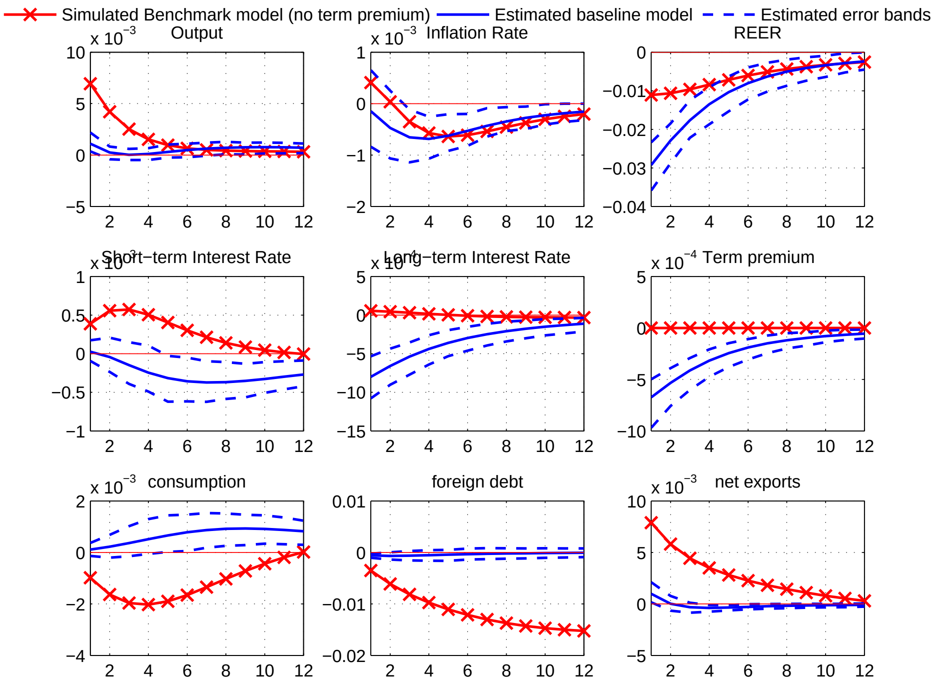


5.2.3 Risk premium shock

Figure 11 presents a risk premium shock. This shock is propagated through the UIP condition causing a rise in long term interest rates and an exchange rate depreciation. It is an important disturbance in the SOE as it depicts changes in foreign investors' sentiment towards the domestic economy. The worsening perception of the domestic economy leads to a financial capital outflow that is reflected in the currency depreciation and a rise in the long term interest rate. The increased long term interest rate hampers consumption, while the depreciation enhances net exports resulting in a GDP growth and an insignificant inflation response. As a consequence short term interest rates are increased by the central bank limiting GDP and inflation growth.

The presence of the term premium leads to a smaller increase in GDP after the positive risk premium shock in my model as compared with the benchmark model. Since the term premium reacts to the external debt, it declines as the domestic economy accumulates claims against the rest of the world. A drop in the term premium lowers the long term interest rate which decreases consumption and weakens the exchange rate depreciation. Both factors are conducive to weaker net exports and push down GDP. The presence of the term premium has a negligible impact on inflation.

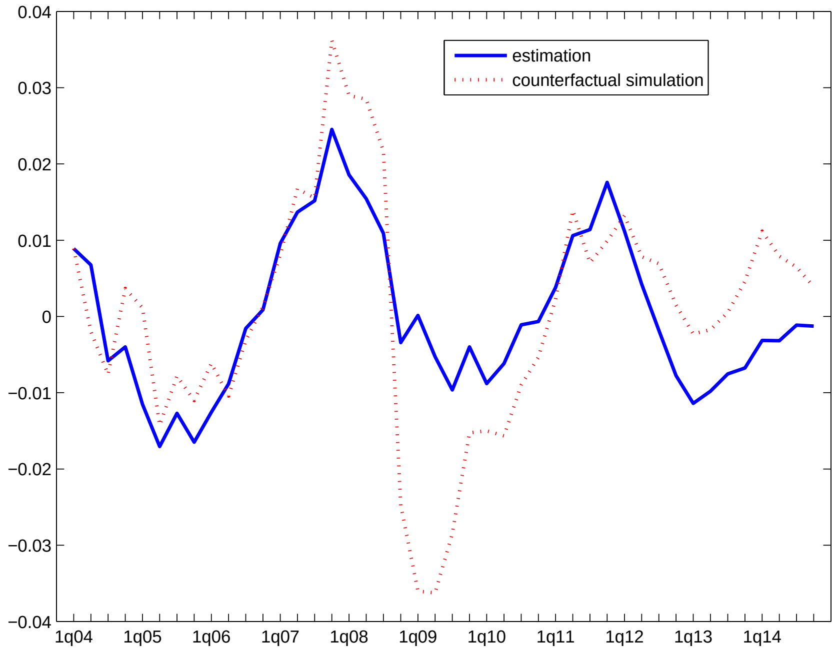
Figure 12: Impulse response functions to an export preference shock



5.2.4 Export preference shock

The export preference shock affects the foreign demand for domestic goods making them more or less desirable for foreigners. The analysis of an export preference shock in both models (Figure 12) leads to similar conclusions as the term premium shock i.e. the term premium supports GDP stability, by reducing consumption and net exports volatilities. It should not come as a surprise due to the similarity of these shocks: both rely on foreign trade channels with the difference that the risk premium shock affects the foreign price of the domestic goods (through the exchange rate), while the export preference shock impacts the foreign demand for domestic goods. As a consequence the risk premium shock leads to an increase in the exporters' revenue, as well as net exports and GDP because domestic goods become cheaper for foreigners, while export preference shock leads to an increase in exports and GDP amidst currency appreciation driven by a higher demand for domestic goods. When the export preference shock hits the economy an increase in foreign demand for domestic goods results in a positive trade balance and - as a consequence - lower external debt. In the model with the term premium the drop in external debt lowers the term premium and the long term rate. Low interest rates support a rise in consumption and weaken the exchange rate leading to weaker net exports. The decline in the trade balance outweighs the positive consumption impact leading to a smaller increase in GDP in the model with the term premium as compared with the model without the term premium.

Figure 13: Historical and counterfactual GDP in Poland



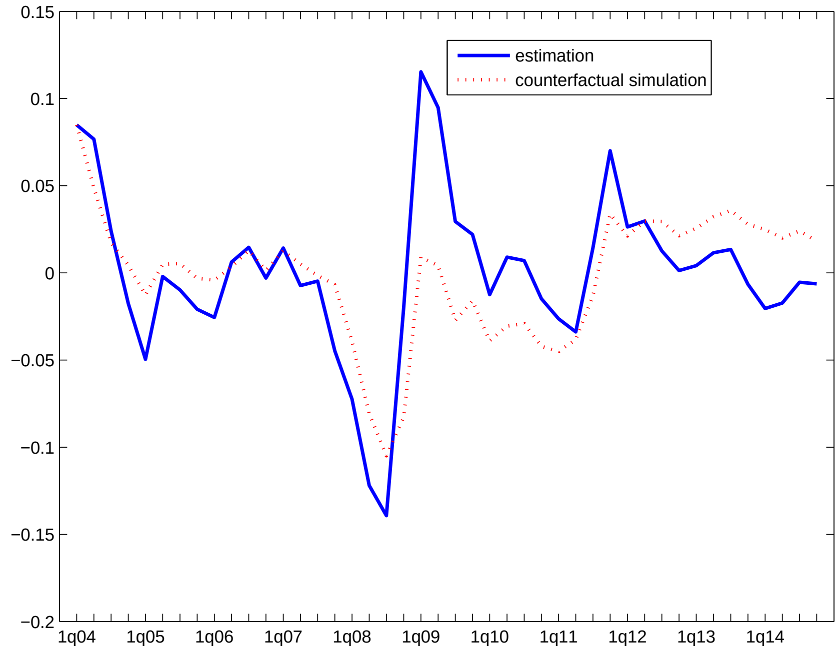
5.3 Historical simulations

In this section I investigate the historical impact of the time-varying term premium on GDP and inflation in Poland. I perform counterfactual simulations in which I substitute my estimated model with the benchmark model that does not contain the term premium. I use historical shocks obtained in the estimation with the exception of the term premium shock that is absent in the model without the term premium.

Figure 13 presents the observed GDP path in Poland (blue line) together with the simulated counterfactual path (red line). It illustrates the stabilizing impact of the term premium found earlier in this section. Without the term premium, GDP volatility would have been much higher especially directly before and during the global financial crisis. This may be a complementary explanation to the stabilizing function of the flexible exchange rate and monetary policy found in Brzoza-Brzezina et al. (2014) since switching off the term premium, in this particular period, reduces the (countercyclical) exchange rate volatility (Figure 14) and as a consequence increases GDP volatility in 2007-2009.

Furthermore, the counterfactual simulation reveals that also in 2013-2014 the term premium stabilized GDP in Poland. During this period the counterfactual path (i.e. with the term premium switched off) is above the historical one amidst the negative term premium. It means that the negative term premium at that time was conducive to the exchange rate appreciation acting contractionary and outweighing the favorable lower term premium impact via consumption.

Figure 14: Historical and counterfactual REER in Poland



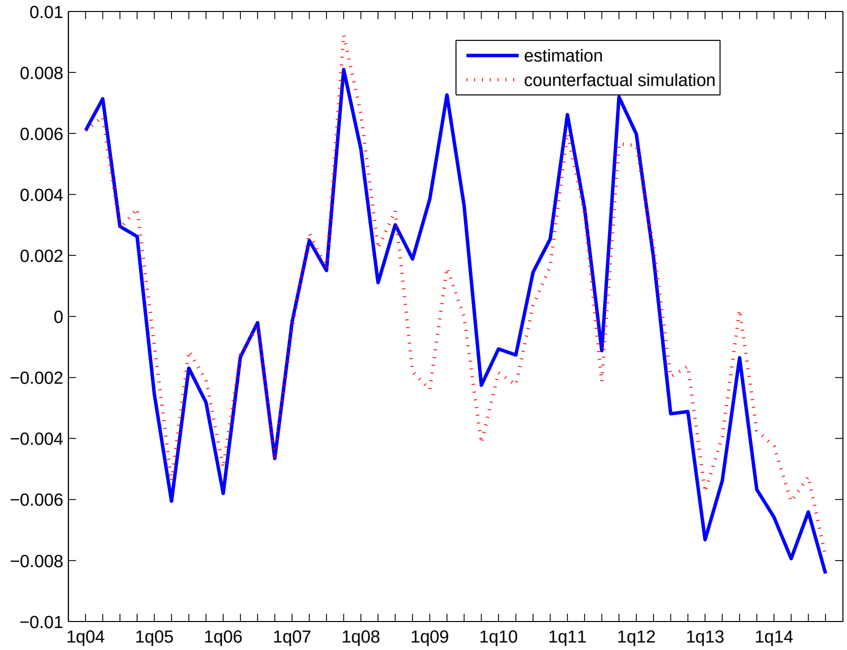
Both examples lead to a conclusion that even tough the endogenous part of the term premium affects both the long term interest rate and the exchange rate, the latter channel is much stronger. Thus, the fall in the endogenous part of the term premium, leading to both fall in interest rate that is expansionary and currency appreciation that is contractionary, is in effect contractionary since the latter channel dominates the former.

The counterfactual behavior of the inflation rate in Poland is somehow different than that of GDP. From the historical perspective it is not clear whether the term premium has stabilized inflation or not. It is understandable taking into account the small stabilization effect as presented in Table 9. It is also in line with the impulse response functions presented in section 5.2 that do not report any significant impact of the term premium presence on the inflation volatility.

Thus, I conclude that the term premium has had a substantial impact on GDP and a minor one on inflation volatilities in Poland. This conclusion is in line with the literature for large closed economies (see section 1). In these models the term premium affects consumption allocation over time and - consequently - GDP through the Euler equation. Since the Philips curve is flat, i.e. the inflation rate does not respond strongly to GDP changes due to e.g. well-anchored inflation expectations, shifts in the term premium affect mainly GDP.

The negative term premium not only supports consumption via the Euler equation, but also dampens net exports due to the exchange rate appreciation. The contractionary impact of the exchange rate outweighs the expansionary influence of the long term interest rate. Thus, the rise in the term premium is expansionary in the SOE instead of being contrac-

Figure 15: Historical and counterfactual inflation in Poland



tionary as it is in the large closed economy.

To sum up, the time-varying term premium stabilizes output at the cost of destabilizing the long term interest rate and exchange rate in Poland (Table 10; up-arrow depicts higher volatility in the model with the term premium). The analysis of IRFs indicates that the stabilization effects of the term premium for the domestic GDP come mainly from the risk premium and the export preference shocks, i.e. shocks that are propagated mainly through the exchange rate and net exports fluctuations. When the time preference shock, i.e. the typical domestic demand shock, hits the economy, in turn, the term premium increases the GDP volatility. Furthermore, the term premium stabilized GDP during the recent financial crisis by impacting the exchange rate. Basing on these results I can answer two research questions: Firstly, the term premium affects significantly how shocks are propagated in Poland. In particular, it impacts economic dynamics when the time preference, the risk premium and the export preference shocks hit the economy. Moreover, the term premium significantly lowers GDP volatility in Poland, whereas its impact on inflation volatility is negligible.

These conclusions refer to the Polish economy, however, some of them may be applicable also for other SOEs. First of all, since the term premium stabilizes GDP for shocks that affect the exchange rate and net exports, while it increases its volatility for domestic demand shock, the relative importance of these two types of shocks should influence the net impact of the term premium on GDP volatility in an SOE. In this context the model estimation for other SOEs would be very interesting. Furthermore, since the term premium seems to stabilize

Table 10: The term premium impact on GDP and inflation volatilties

Shock name:	GDP	c	π
Time preference	$\uparrow$	$\downarrow$	$\leftrightarrow$
Risk premium	$\downarrow$	$\downarrow$	$\leftrightarrow$
Export preference	$\downarrow$	$\downarrow$	$\leftrightarrow$
Productivity	$\leftrightarrow$	$\leftrightarrow$	$\leftrightarrow$
Monetary policy	$\leftrightarrow$	$\leftrightarrow$	$\leftrightarrow$

the consumption volatility when the impact of the first type of shocks prevails, it also should increase welfare in this case. Such a hypothesis requires a second-order approximation of the model with the term premium that would allow for welfare analysis. I leave these issues for further research.

6 Summary

In this article, I investigate how strongly the long term interest rate that includes the time-varying term premium impacts GDP and inflation in Poland. In particular, I use the estimated DSGE model of an SOE to show the significant impact of the term premium on impulse responses for the risk premium and the export preference shocks. When these shocks hit the economy the term premium stabilizes external debt volatility by reacting endogenously to its changes. Consequently, responses of net exports and other macroeconomic variables, in particular GDP, to these shocks are much more muted. On the other hand, when the time preference shock hits the economy, a rise in the term premium dampens consumption and imports leading to an increase in net exports. The effect of the rise in net exports dominates over the effect of consumption drop resulting in stronger GDP growth than would be the case in the absence of the term premium.

Furthermore, I prove that historically the term premium reduced the output volatility in Poland, while it did not affect significantly the inflation rate volatility. This conclusion refers especially to the recent global financial crisis period: if the term premium had been switched off at that time, the GDP volatility would have been much higher. On the other hand, the term premium shock had a minor impact on GDP and inflation volatilities which suggests, among others, that the QE programs conducted by the major central banks did not have a substantial impact on the Polish economy even though they significantly lowered long-term interest rates in Poland. According to my estimation, the central bank short-term interest rate has a 5.1-fold stronger impact on the output gap in Poland than the 10-year long term interest rate.

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