COLLEGIUM OF ECONOMIC ANALYSIS
WORKING PAPER SERIES

The non-linear nature of country risk and its implications for DSGE models

Michał Brzoza-Brzezina and Jacek Kotłowski

The non-linear nature of country risk and its implications for DSGE models[*]

Michał Brzoza-Brzezina[†], Jacek Kotłowski[‡]

Abstract

Country risk premia can substantially affect macroeconomic dynamics. We concentrate on one of their most important determinants - a country's net foreign asset position and - in contrast to the existing research - investigate its nonlinear link to risk premia. The importance of this particular non-linearity is twofold. First, it allows to identify the NFA level above which the elasticity becomes much (possibly dangerously) higher. Second, such a non-linear relationship is a standard ingredient of DSGE models, but its proper calibration/ estimation is missing. Our estimation shows that indeed the link is highly nonlinear and helps to identify the NFA position where the non-linearity kicks in at approximately -70% to -75% of GDP. We also provide a proper calibration of the risk premium - NFA relationship which can be used in DSGE models and demonstrate that its slope matters significantly for economic dynamics in such a model.

JEL: C23, E43, E44
Keywords: Risk premium, PSTR model, open economy DSGE model

1 Introduction

Country risk premia have the ability to substantially affect macroeconomic dynamics in open economies. This is particularly the case when spreads shoot up (as they did for instance in Greece in 2012) effectively cutting the economy off from borrowing. What stands out in this context is the potential of risk premia to generate a debt spiral. If a country is highly indebted investors may fear about its solvency. As a consequence risk premia could rise, increasing debt servicing costs and, as a consequence, possibly further increasing foreign debt. This mutual relationship may not only have bearing consequences for indebted countries, but also make the relationship between foreign debt and risk premia highly non-linear.

Given their importance, risk premia have received substantial attention in the literature, both empirical and structural (DSGE). Empirical papers concentrate on finding the determinants of country risk. The list of related papers is long and includes i.a. Ferrucci (2003); Ciocchini et al. (2003); Baldacci and Kumar (2010) and Bellas et al. (2010). Fouejieu and Roger (2013) provide an extensive literature review on the topic. These studies point at a number of important risk premium determinants, including the fiscal balance and debt, foreign debt or net foreign assets, political stability, exchange rate volatility, financial sector characteristics, the ability to borrow in domestic currency or external liquidity conditions. Several papers point out the crucial role of foreign debt, however it usually enters the estimated equations in a linear fashion. To motivate our case we present on Figure 1 the scatterplot of our two main data series - the interest rate differential between a country's and the United States long term bonds and its net foreign asset position. The non-linear relationship is evident, although one should remember that this picture does not control for other, possibly important factors.

In the DSGE literature risk premia play a very important role - following Schmitt-Grohe and Uribe (2003) endogenous risk premia, driven by a country's net foreign asset (NFA) position are used to pin-down foreign debt and allow for solving DSGE models of small, open economies (e.g. Adolfson et al. 2007; Christoffel et al. 2008; Garcia-Cicco et al. 2010; Justiniano and Preston 2010; Benczur and Konya 2015). The source of the problem is that without an endogenous premium a small, open economy could borrow any amount at the world interest rate.

As already explained, the NFA position plays a crucial role in both streams of the literature. However, both streams miss something important. The empirical literature mentioned above has so far concentrated on modeling a linear relationship between the risk premium and NFA (or gross foreign debt) position. This misses the crucial problem of nonlinearities. The DSGE literature in contrast, usually focuses on a non-linear (e.g. exponential)

relationship, however it neglects its calibration.[1] This may bias the models dynamics.

In this paper we focus our attention on the non-linear relationship between the risk premium and the NFA position of a country. We see two important contributions, one for policy and one for modeling. Both are not offered by linear models. First, from the policy perspective our estimates help to determine the regions where the premium becomes particularly elastic to debt and - as a consequence - the economy risks falling into a debt spiral. From the modeling perspective, we offer a ready-to-use calibration of the risk premium - NFA relationship that can be applied in DSGE models. Of course one has to bear in mind that the relationship offers rather a shortcut than a structural linkage. From this perspective our results could also be considered as motivation to provide a structural derivation of this link in the DSGE literature. Our results could then serve as a check whether the derived link is in line with empirical evidence.

The paper consists of two parts. In the first we estimate a non-linear model of the risk premium, focusing primarily on its relationship with the NFA position. We collect data for 41 advanced and emerging economies and show that indeed the link is highly non-linear. For positive and mildly negative NFA positions the risk premium to NFA elasticity is slightly negative. However, once NFA worsens further the elasticity decreases substantially. We identify the level at which strongest nonlinearities kick in at approximately -70% to -75% NFA to GDP ratio. At this level of foreign debt the semi-elasticity of spreads with respect to NFA increases thirteen-fold compared to normal times. As a consequence a country can be caught in a debt trap.

The second part adapts the estimated relationship to the structure of a typical DSGE model. Such relationships have for a long time constituted an important ingredient of small open economy DSGE models. However, their calibration was supposed to provide model stability rather than reflect the elasticities found in the data. We fill this gap. Moreover, we show on the basis of a standard two-economy DSGE model that taking into account the non-linear risk premium - NFA relationship has important consequences. First, it allows to take into account diverging rates of time preference in a way that is consistent with a well parametrized steady state. Second, we show that model dynamics differ significantly depending on steady state debt. Third, we document how the DSGE model with our estimated risk premium specification differs form models with calibrations/ estimations known from the literature.

The rest of the paper is organized as follows. Section 2 discusses the data and Section 3 our econometric procedure and results. Section 4 discusses the application of our results for

---

[1] Notable exceptions are Garcia-Cicco et al. (2010) and Miyamoto and Nguyen (2017) who estimate RBC models including the risk premium function. However, as will be explained later, their estimations do not treat risk premia as observable variables.

DSGE modeling. Section 5 concludes.

2   Data

We collect annual data for 41 advanced and emerging economies (see Table 1 for a list). Our panel extends from 1991 to 2014, is however unbalanced due to limited availability of data on long-term interest rates. Our dependent variable is defined as the difference between a country's long-term interest rate and the rate for the United States. There are two options regarding the choice of bonds - denominated in domestic or in foreign currency and both have advantages and drawbacks. Foreign currency denominated bonds are better at approximating country risk, as their valuation does not include exchange rate risk or expected currency depreciation (which are priced in domestic currency bonds). Bonds denominated in domestic currency are, however, usually more liquid, moreover, some countries issue only domestic currency debt. We decided to use bonds denominated in domestic currency while controlling for factors that determine exchange rate risk and expected exchange rate depreciation.[2] To this end we add exchange rate volatility and the inflation differential as explanatory variables to the model. The data on yields comes from International Financial Statistics and Bloomberg and in most cases represents the yield on 10-year government bonds. For a few countries, where 10-year bonds were missing we approximate the spread using 5-year bonds.

Following the literature we use the following set of explanatory variables:

- Net foreign asset to GDP ratio - the data is drawn from the IMF's database constructed for the External Balance Assessment exercise (IMF, 2013). The series is and update on the NFA statistics provided by Lane and Milesi-Ferretti (2001).

- General government gross debt to GDP ratio (source: World Economic Outlook)

- General government net lending to GDP ratio (source: World Economic Outlook)

- CPI inflation (differential to US inflation) (source: World Development Indicators)

- GDP per capita (at purchasing power parity) relative to the US (source: World Economic Outlook)

- Exchange rate volatility (unconditional volatility based on monthly data) (source: Bank for International Settlements and International Financial Statistics)

- Goldman Sachs US Financial Conditions Index (source: Bloomberg)

---

[2]Using foreign currency denominated bonds would reduce our sample by 20%. Nevertheless, we conducted an additional set of estimations on such a sample, and the results were mainly untouched.

- Slope of the US yield curve (source: Bloomberg)[3]

- VIX (source: Chicago Board of Trade)

It has to be emphasized that our dependent variable is a proxy rather than a direct measure of the country risk premium. As already mentioned, beyond country risk this variable may for instance contain an exchange rate risk component. Moreover, formally it refers to sovereign debt and as such does not cover the private sector. Data limitations are the main reason, why (in line with much of the literature) we need to make such compromise. We believe that our control variables help to reduce the problem.

3 Model and estimation

3.1 Econometric approach

We assume a non-linear relationship between a country's risk premium and the value of its net foreign assets. In particular we expect that the semi-elasticity of the risk premium with respect to its NFA position increases as the latter variable falls. We capture this non-linear relationship using a panel smooth transition regression (PSTR) model as proposed initially by Granger and Teräsvirta (1993) and Teräsvirta (1994) for time series and cross sectional data and extended by González et al. (2005) for panel data. The model allows for switching between two regimes, which depend on the level of the country's external indebtedness.

We start from a general form of non-linearity and test for the distribution of the transition function. Therefore we formulate a fixed effects PSTR model which takes the general form:

$$y_{it} = \mu_i + \delta_1 NFA_{it} + G\left(s_{it}; \gamma, c\right) \cdot \delta_2 NFA_{it} + \beta' x_{it} + u_{it}, \tag{1}$$

where $G(s_{it}; \gamma, c)$ is a transition function allowing for the non-linear relationship between the country's risk premium y_{it} and its net foreign assets position (NFA_{it}). Moreover x_{it} stands for the vector of other variables affecting the risk premium (as listed in Section 2), μ_i express the fixed individual effects and u_{it} are the error terms. We investigate two alternative transition functions usually proposed in the literature, the logistic function:

$$G(s_{it}; \gamma, c) = (1 + \exp\{-\gamma(s_{it} - c)\})^{-1}; \quad \gamma > 0 \tag{2}$$

and the exponential function:

$$G(s_{it}; \gamma, c) = 1 - \exp\{-\gamma(s_{it} - c)^2\}; \quad \gamma > 0. \tag{3}$$

---

[3]We calculate the slope of the US yield curve as a difference between US money market rate and 10-year US Treasury bond yield.

The variable s_{it} in (2) and (3) is the transition variable, c is a threshold parameter, and γ is a transition parameter, which measures the speed of transition from one regime to the other. The restriction $\gamma > 0$ is an identifying restriction.

The transition functions described by (2) and (3) are bounded between 0 and 1. It means that the parameter measuring the semi-elasticity of the risk premium with respect to the net foreign asset position may vary between δ_1 and $\delta_1 + \delta_2$ along with the transition variable s_{it}. The logistic function (2) approaches zero for very large negative values of the transition variable and approaches one for very large positive values. The exponential function (3) converges to unity for very large both positive and negative values of the transition variable s_t and is close to zero when s_t is equal to the value of the threshold parameter c. As a consequence our functional form allows to accommodate a wide range of shapes.

We assume that the semi-elasticity of the risk premium with respect to the country's NFA position depends on its NFA stock. Therefore the transition variable s_{it} in equation (1) reflects the net foreign assets position and the PSTR model boils down to:

$$y_{it} = \mu_i + \delta_1 NFA_{it} + G\left(NFA_{it}; \gamma, c\right) \cdot \delta_2 NFA_{it} + \beta' x_{it} + u_{it}, \qquad (4)$$

If the PSTR model with the logistic transition function (2) is validated, it implies that the changes in external debt influence the risk premium to a different extent when the debt is low and when it is high. On the other hand, when the exponential transition function (3) is validated the semi-elasticity of the risk premium with respect to external debt changes (probably rises) as debt increases but after exceeding a certain debt level it returns to the initial level. While such shape seems a priori somewhat less likely, we do not want to exclude this possibility. Low elasticities for deeply negative NFA positions could for instance result from investors expectations of international financial support programs or a decision of debt restructuring not yet evidenced in NFA data.

Figures 2 and 3 present examples of possible relationships between the risk premium and NFA for the logistic and exponential transition functions. Note that estimation of the PSTR model allows not only to determine the type of transition function but also the speed of transition between the regimes.

We proceed in two steps adopting the method proposed by Escribano and Jordá (2001), which allows to distinguish between two alternative transition functions: the logistic and the exponential one. First we test for the presence of general PSTR non-linearity in the form proposed by model (4) against the linear panel model. Model (4) is linear if $\gamma = 0$ or $\delta_1 = \delta_2$. However under both hypotheses the PSTR model contains unidentified parameters and the respective tests are non-standard (see Hansen, 1996 and Luukkonen et al., 1988 for discussion). Therefore we approximate the non-linearity in model (4) by the second order Taylor series expansion of the PSTR model with exponential transition function around

$\gamma = 0$, which is the auxiliary regression for the proposed Escribano and Jorda test:[4]

$$y_{it} = u_i + \delta NFA_{it} + \beta' x_{it} + \lambda_1 NFA_{it}^2 + \lambda_2 NFA_{it}^3 + \lambda_3 NFA_{it}^4 + \lambda_4 NFA_{it}^5 + u_{it}, \quad (5)$$

The null hypothesis of linearity is:

$$H_0 : \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = 0$$

and may be tested using Wald or LM type statistics.

Once the linearity is rejected the next step is to select between the PSTR model with the logistic or exponential transition functions. Therefore, following Escribano and Jordá (2001), we test two hypotheses:

$$H_{0L} : \lambda_1 = \lambda_3 = 0$$

and

$$H_{0E} : \lambda_2 = \lambda_4 = 0$$

We choose the PSTR model with logistic (exponential) transition function if the minimum p-value is obtained for H_{0L} (H_{0E}), conditionally on rejecting linearity.

After the transition function has been selected we estimate the parameters of the non-linear model (4). For the smooth transition regression model with fixed effects González et al. (2005) propose the application of the within estimator and non-linear least squares (NLS). As for the linear within estimator we remove first the fixed effects from the model by subtracting the individual specific means from the data. Then we apply the non-linear least squares estimator to the transformed variables.

The algorithm which allows to compute the within estimator for the panel STR model differs slightly from the linear case. Since the model is non-linear the values of some explanatory variables in (4) depend on the parameters of the transition function c and γ. Therefore respective explanatory variables and their individual specific means are varying with the iterative estimation of the parameters of the transition function. For that reason they have to be recomputed at each iteration (see González et al., 2005 for details).

---

[4]González et al. (2005) propose the testing procedure where the non-linear (logistic) transition function in equation (1) is approximated by the first order Taylor series expansion. Since we would like to test the general non-linearity first and then select between the transition functions we do not follow this procedure, which implies ex ante the logistic distribution of the transition function.

3.2 Estimation results

We start the analysis by specifying the linear model first. We estimate a static fixed effects model with standard errors corrected for the presence of autocorrelation and remaining heteroscedasticity. The estimation results are collected in Table 2. Our estimates seem consistent with economic intuition and the literature. The risk premium is affected by both country specific and global factors. It depends positively on the general government debt and on the inflation differential. We also observe a positive relationship with exchange rate volatility. Furthermore the estimation outcome shows that the yields differential decreases as the real convergence process occurs. We evidence that the progress in the stage of convergence expressed by the relative GDP per capita limits a country's risk premium. The premium is also negatively affected by the general government balance. The country risk spreads are also influenced by the global factors. The spreads are rising during financial turmoil periods, which is captured in the model by the positive relationship with Goldman Sachs US Financial Conditions Index and negative one with the slope of the US yield curve.

At this point the issue of potential endogeneity of the explanatory variables has to be raised. As far as the fiscal variables are concerned this problem seems to be negligible since the change in long-term yields differential affects the current level of debt and fiscal deficit only to a minor extent. That is because the change in long-term yields influences only the costs of the debt service for the new issuance of the long-term sovereign bonds, which constitutes usually only a small part of the whole debt service costs. We also do not expect the endogeneity problem in case of the net foreign assets position since we use the NFA stock measured at the end of the preceding year. We believe that the only explanatory variable which may be endogenous in our model is the variable representing the exchange rate volatility[5]. To address the problem of potential endogeneity we instrument this variable by its first differences, its squares as well as by the VIX index measuring the level of risk aversion on the global financial markets.

The results for the model with instrumented exchange rate volatility variable have been collected in the second column of Table 2. The Sargent J-test fails to reject the hypothesis about the proper choice of instruments at the 5% significance level. The results for the model with instrumental variables do not differ substantially as compared with the estimation results for the model estimated with OLS presented in column 1. Only the coefficient estimate for exchange rate volatility is slightly smaller. The choice of the estimation method does not alter the coefficient estimates for other variables.

---

[5]Gumus (2013) argues that the effect of exchange rate fluctuations on the country's default risk priced in the the yields on sovereign bonds may be substantial in particular in case of emerging economies with relatively high share of foreign currency denominated debt while the exchange rate movements increase the costs of debt service raising the probability of country's default.

As a next step we test for the potential non-linearity in the relationship between the net foreign assets position and the country's risk premium using the algorithm described in Section 3.1. First we estimate the second order Taylor series expansion for the PSTR model with exponential transition function, which is the auxiliary regression for this test. We verify the joint statistical significance of the variables being the subsequent powers of NFA from the second to the fifth power in equation (5). We collect the outcomes of this test in Table 3. We follow this testing procedure for the model estimated with OLS (columns 1 and 2 in Table 3) and for the alternative model, in which the exchange rate volatility has been instrumented (columns 3 and 4). The appropriate test statistics allow rejecting the null hypothesis of linearity in favor of general STR type non-linearity at any conventional significance level for both investigated models.

Once linearity has been rejected we select further between the logistic and exponential transition function in the PSTR model. The outcome of this test for our basic fixed effects model estimated with OLS (columns 1 and 2 in Table 3) as well as with IV method (columns 3 and 4 in Table 3) clearly suggests the choice of the logistic function as the appropriate transition function. The p-values for the respective hypotheses are significantly lower than for the hypotheses implying the validity of the exponential function.Thus we choose the logistic function as the transition function in the PSTR model.

Accordingly we derive the coefficients of the model with OLS and with the IV method to check for potential endogeneity of the exchange rate volatility. We use the same instruments as in the previous steps: first differences of the exchange rate volatility, its squares and the VIX index. The estimation results for both models are presented in Table 4.

In the first column we present the fixed effects model estimated with non-linear OLS while in the second column we show the fixed effects model estimated with non-linear LS with instrumental variables. Moreover in the third and fourth columns we show the results for the model including the year dummies. The results validate the choice of the PSTR model with the logistic transition function. The parameter reflecting the non-linear impact of the NFA position on the risk premium is statistically significant at 5% significance level.

As pointed out in Section 3 the choice of the logistic transition function implies that the (negative) parameter measuring the influence of the net foreign assets stock on the yields differential decreases as NFA declines. The results for the fixed effects model estimated with non-linear OLS (column 1 in Table 4) show that the impact of the changes in NFA stock on the country's risk premium increases significantly (in modulus) as NFA approaches ca -74% of the country's GDP. For NFA values lower than this threshold level the worsening in the NFA position by 10 p.p. results in an increase of the risk premium by ca. 20 bps. It is worth to remind that this effect is almost twice as large as for the linear model discussed previously. For NFA levels below the threshold the semi-elasticity of the risk premium is

only negligible. The worsening in the NFA position by 10 p.p. results in an increase of the risk premium by only 1.6 bps. (the sum of coefficients $\delta_1 + \delta_2$ equals -0.16 – see Table 4). The semi-elasticities are presented on Figure 4.

In line with the literature our estimation confirms the impact of several other variables on the risk premium. The semi-elasticity of the risk premium with respect to inflation differential is 0.52 which means that the increase of country's inflation relative to US inflation transmits to the long term yields differential only by a half (column 1 in Table 4). While this is much below the unit parameter that could be expected, one should remember that current inflation is probably an imprecise proxy for long term inflation expectations. The semi-elasticity of the public debt is relatively low and equals 0.017 – the growth of general government debt to GDP ratio by 1 p.p. raises the yields differential by 1.7 bps. The reaction of the investors to changes in the general government balance is stronger but statistically significant only at the 20% significance level. The improvement of the fiscal balance by 1 p.p. reduces the yields differential by ca. 3.6 bps. It is worth to note that both fiscal variables are correlated with each other because the improvement of the fiscal balance might lead to the reduction of the borrowing needs and furthermore to decrease of public debt. Hence the isolated impact of each of these variables may be stronger. Moreover the exchange rate volatility and the variable expressing the country's GDP per capita level are statistically significant with expected signs. The country's risk spreads are also influenced by the global factors represented in our model. The increase of the Goldman Sachs US Financial Conditions Index affects the country spreads positively, which means that during financial turmoil risk premia tend to rise. Furthermore the steepening of the US yield curve leads to the increase of country's risk spreads. The most likely explanation of this result is that the increase of the term premium included in the long term US Treasury bonds yields corresponds to higher risk aversion on the global financial markets and results in the widening of the country spreads.

It is worth noting that the results for the fixed effects model estimated with instrumental variables are very close to the OLS estimates. The only slight difference concerns the parameter estimate related to exchange rate volatility being instrumented in the second model, which is smaller than in the OLS estimation.

3.3   Robustness checks and extensions

We do a number of robustness checks and extensions of the baseline framework, but they do not change our main findings. Below, we report the two that we find most important.

First we extend the fixed effects PSTR model (5) for time (year) dummies to capture potential commons trends. The estimation results for this model are presented in the third and fourth columns of Table 4. The findings are similar to the basic model with the exception

of the variable reflecting the fiscal balance, for which the standard error rises substantially. The semi-elasticities of the risk premium with respect to the NFA position are only about 5% larger than in the basic models and remain statistically significant.

Second we check whether the threshold level of the NFA position (reflected by the constant term in transition function (2)) at which the foreign indebtedness starts affecting the country's risk premium more seriously, may be different for advanced and emerging economies. In other words we verify the hypothesis that investors are more tolerant in the assessment of country's credit risk with respect to its level of foreign debt for developed than for developing countries. To test this hypothesis we include into the PSTR model a dummy variable, which differentiates the threshold level of the NFA position between emerging and advanced economies. The transition function in the PSTR model capturing this feature has then a following form:

$$G(s_{it}; \gamma, c) = (1 + \exp\{-\gamma(s_{it} - c - c_1 \cdot AE_i)\})^{-1}; \quad \gamma > 0 \qquad (6)$$

where AE_i is a variable which takes value one for advanced economies and zero otherwise. The classification of the respective economies follows the IMF classification and has been included in Table 1.

The estimation results are presented in the fifth and sixth columns of Table 4. The dummy variable which differentiates the NFA threshold level between advanced and emerging economies proves to be statistically significant but the magnitude of its impact on the country's risk assessment is rather small. The estimated threshold levels of the NFA positions for developed and emerging economies differ by only ca. 4-4.5% of GDP. In line with our expectations this level is higher for emerging economies and amounts to ca. 70% of GDP. The parameter estimates for other control variables in the extended model are very close to the numbers obtained in our basic model. All in all, these results lead to the conclusion that the perception of certain economy as being advanced or developing per se does not strongly affect the threshold level at which the non-linearity in country's risk assessment kicks in.

4   Consequences for DSGE models

The relationship on which our study focuses - between the country risk premium and its net foreign asset position plays an important role in constructing and solving DSGE models. In what follows we concentrate on three problems: (i) what are the implications of our relationship for the model's steady state, in particular for rates of time preference, (ii) how does the non-linearity in our estimated relationship affects the model dynamics and (iii) how does our function compare with the most popular relationships used so far in the literature.

The Section begins by adjusting our estimated relationship to being used in DSGE models. Then we briefly introduce our model. Finally, we analyze the three problems listed above.

4.1   A simple rule

As explained in detail by Schmitt-Grohe and Uribe (2003), models of small open economies may suffer from indeterminacy. This is because in a standard framework nothing pins down the small open economy's foreign debt level. Schmitt-Grohe and Uribe (2003) offer a number of solutions to this problem, i.a. endogenous discount factors, convex portfolio adjustment costs or a debt elastic country interest rate premium.

The last solution has been found particularly popular, several small open economy DSGE models have been solved by adding this feature (e.g. Adolfson et al. 2007; Christoffel et al. 2008; Justiniano and Preston 2010; Garcia-Cicco et al. 2010). The original specification, from which most future studies borrow is as follows:

$$\rho_t = 1 + \psi \left(exp(d_t) - 1 \right) \tag{7}$$

where ρ_t denotes the risk premium as specified in DSGE models (details below), d_t is the net foreign debt to GDP ratio and ψ a positive parameter.[6]

Under such a function foreign debt is pinned down in steady state and the positive slope of the function guarantees its stability. What is problematic is the calibration of ψ. For many countries time series of risk premia are too short to allow for a successful time series estimation. Even less promising seems finding the parameter via system estimation of the whole DSGE model. First, such estimation does usually not feature control variables which, as we show, are important determinants of the premium. Second, for technical reasons estimation of DSGE models is conducted for their linearized version. However, we have shown, that the relationship is strongly non-linear.

In what follows we transform the OLS-estimated non-linear relationship so that it can be directly applied in DSGE models. The transformation takes into account the following issues:

- In contrast to our econometric specification, DSGE models usually do not feature control variables like exchange rate volatility. We keep them in the estimation to avoid biased parameters, but ignore them in the final specification.

---

[6]The functional forms usually additionally include a shift factor that allows to set the steady state debt-to-GDP ratio to an exogenously determined level. To keep things simple, in what follows, we ignore this element without loss of generality.

- Most of the DSGE models under consideration are of quarterly frequency and the premium is expressed in gross terms. We adjust the parameters accordingly to make it compatible with models where for instance $\rho_t = 1.0025$ is a 25 basis point premium expressed on quarterly basis.

- DSGE models usually contain a net foreign debt variable instead of net foreign assets. The variable is expressed relative to quarterly GDP.

Then our relationship is:

$$\rho_t = 1 + d_t \left\{ \psi_1 + \psi_2 \left[1 + exp\left(\psi_3 \left(d_t - \psi_4 \right) \right) \right]^{-1} \right\} \tag{8}$$

This relationship is non-linear and as such can be used directly for studying deterministic model dynamics. It should be noted, that given the relatively fast transition between the two regimes (see Figure 4) for stochastic purposes the relationship can be linearized around the appropriate steady state without much loss of accuracy. The only problematic area is the vicinity of our threshold debt ratio (approximately 300% of quarterly GDP). Then the relationship can be simplified to:

$$\rho_t = 1 + \psi_5 d_t \tag{9}$$

where

$$\psi_5 = \begin{cases} \psi_1 + \psi_2 & \text{for } d_t \ll 3 \\ \psi_1 & \text{for } d_t \gg 3 \end{cases}$$

The parameters of equations (8) and (9) after being slightly rounded are given in Table 5.

4.2 The model

A natural question emerges, whether and how these estimates matter for DSGE modeling. This will be analyzed on the basis of a standard two economy new Keynesian model. The model consists of two symmetric economies, both populated by households, intermediate and final good producers and a central bank. Households derive utility from leisure and consumption, can save in domestic and foreign bonds and accumulate capital. Producers use labor and capital rented from households to produce differentiated intermediate goods. These are exported or sent to the domestic market. At this stage prices are sticky a la Calvo in local (consumer) currency. Final goods are aggregated from domestic and imported goods and used for consumption and investment purposes. The central bank follows a Taylor rule. The detailed problems faced by households, producers and the monetary authority are presented in the Appendix.

The calibration strategy is subordinated to the main goal of this section, to document the working of the non-linear risk premium function. Given this goal the calibration of structural parameters is fully symmetric, the only difference being the size of the two economies (so that one is large and closed and the other small and open). Consequently the calibration reflects rather generic than specific small and large economies. In particular Calvo probabilities and habits are set to 0.75, the intertemporal elasticity of substitution is 2, the smoothing parameter in the Taylor rule is 0.75, the response to inflation 2 and the response to output 0.125, roughly in line with much of the empirical DSGE literature (e.g. Smets and Wouters 2005; Adolfson et al. 2007). The elasticity of substitution between home and imported goods in the final aggregate is set to 4 (which implies $\mu = 1.33$). The small economy is assumed to produce 1% of world GDP and its openness (share of imports in final good) is calibrated at 30%. Calibrated parameters are presented in Table 6.

A final issue is related to the calibration of the risk premium function. Our baseline will be equation (8) with its calibration given in Table (5). However, in what follows, we will also refer to alternative specifications from the literature. In particular, we will use the calibration of relationship (7) from Schmitt-Grohe and Uribe (2003) ($\psi = 0.000742$). We will also refer to two papers that have recently attempted to estimate the risk premium function coefficient together with other parameters of a DSGE model using a full-information approach. Garcia-Cicco et al. (2010) used a long series of Argentinean data (1900-2005) to estimate the parameters of a small open economy real business cycle model. The estimation yields a relatively high posterior median for $\psi = 2.8$. Miyamoto and Nguyen (2017) use equally long series and estimate a similar model for 17 developed and developing countries. They use a slightly different functional form, so that a direct comparison of coefficients is not possible. In general, for plausible values of debt, the slopes of the premium-debt relationship for most countries in their sample are only slightly lower than in Garcia-Cicco et al. (2010) and substantially higher than in Schmitt-Grohe and Uribe (2003) or our case.

4.3   Steady state issues

Let us start with the steady state. To better understand what the relationship between the risk premium and the NFA position implies for the model let us consider the UIP condition (A.5) in the steady state (non-indexed variables denote steady state levels):

$$\frac{R}{\pi} = \rho \frac{R^*}{\pi^*} \tag{10}$$

Substituting for R and R^* from the consumption Euler equations (A.4) at home and abroad yields the relationship between the risk premium and rates of time preference:

$$\rho = \frac{\beta^*}{\beta} \tag{11}$$

Given the link between the NFA position and the risk premium (8) a zero steady state NFA position is consistent with equal rates of time preference. On the other hand non-zero debt is compatible only with diverging levels of patience.[7] Importantly, with a reasonably parametrized risk premium function diverging time preference rates imply a non-degenerate steady state with a plausible NFA position. For instance assuming $\beta^* = 0.99$ and $\beta = 0.985$ (i.e. an annualized two percent premium) implies an annualized steady state debt-to-GDP ratio of roughly 100%. For comparison, the elasticity estimated by Garcia-Cicco et al. (2010) would imply a mere 1% debt-to-GDP ratio in this case. Reversing the calculation, a 100% debt-to-GDP ratio would imply a rather unrealistic premium of 481%. We explain why these estimates (and their implications) differ that much from ours in Section 4.5.

Diverging rates of time preference have not received much attention in the literature yet. However, as shown by Falk et al. (2015) time preferences differ substantially between countries. This may have important consequences for a broad range of macroeconomic issues, including economic growth (Dohmen et al., 2016), monetary policy (Fagan and Gaspar, 2007) or external imbalances. A simple but well parametrized link can offer a useful shortcut to analyze such problems.

4.4   Comparison of two slopes

In this Section we check whether the estimated non-linearity matters in practice. To this end we compare the dynamics of our model for the two slopes of the risk premium function (9).[8] We consider two shocks - a standard supply shock to productivity σ_z and a standard demand shock to preferences σ_u.

Figure 5 presents the reaction of the small economy to a negative productivity shock that generates a 2.5% decline in output. Since households smooth consumption and adjusting investments is costly both these variables decline by less than output. The impact is smoothed out thanks to net exports which decline, as a consequence foreign debt increases. Here the stories begin to differ depending on the premium elasticity. If the elasticity is low the premium increases only slightly. As a result the economy is not prevented from taking more debt - net exports and NFA decline strongly and consumption and investments decline much

---

[7]We ignore the intellectually unappealing possibility to exogenously set the steady state debt by adding a shift factor to the risk premium equation and instead concentrate on the more interesting structural explanation, according to which less patient countries are indebted.

[8]The simulations presented below use the linear relationship (9) and (somewhat counterfactually) assumes zero debt in steady state. This technical assumption allows us to concentrate on the role of the slope, separating it from the impact of interest payments on past debt. Nevertheless, we will call the low (high) elasticity economy low (high) debt economy.

less than for the high-debt economy. Interestingly, for the productivity shock the domestic demand vs. net exports effect cancel out so that the impact of the shock on output is similar in both cases.

After a demand (preference) shock (Figure 6) consumption rises, one of the consequences being higher imports and rising foreign debt. Again, in the low-elasticity economy this generates only a moderate increase of the risk premium. If the elasticity is high the risk premium rises more sharply. As a consequence, in the latter case the interest rate (not shown) increases by more, crowding out investments. In contrast to the productivity shock, now domestic demand and net exports do not cancel out, so that also GDP reacts differently for the two economies.

While the specific patterns clearly depend on the shock, two common conclusions can be drawn. First, the reactions may differ substantially, depending on the slope of the risk premium function. Second, the differences for national account components are more pronounced than for GDP. In general, the steeper the slope, the stronger the impact of shocks on the domestic economy and the weaker on net exports.

4.5 Comparison to the literature

Another interesting and important question is, how our estimates relate to those used previously in the DSGE literature. As already mentioned, the most popular functional form for the risk premium - foreign debt relationship used in the literature is exponential (7). In most cases parameter ψ is calibrated to small values to ensure that the risk premium does not affect model dynamics (e.g. Christoffel et al. (2008) use $\psi = 0.01$). However, the estimated values of Garcia-Cicco et al. (2010) and Miyamoto and Nguyen (2017) are much higher.

Two questions emerge. First, whether the differences matters for model dynamics. Second, why are estimated coefficients so different between our model and the two estimated general equilibrium models.

The answer to the first question has already been already suggested by our previous exercise, where we showed that our two different slopes imply different model dynamics. We compare impulse responses to a productivity shock under four different assumptions about the risk premium - debt relationship, stemming form our estimation, estimations of Garcia-Cicco et al. (2010) and Miyamoto and Nguyen (2017) as well as the calibration of Schmitt-Grohe and Uribe (2003).[9] Figure (7) shows the results. Clearly impulse responses differ substantially. In particular the estimated functions of Garcia-Cicco et al. (2010) and Miyamoto and Nguyen (2017) imply stronger reactions of domestic demand and much weaker

---

[9]The results are shown for slopes consistent with an annualized debt-to-GDP ratio of 80%, but our findings are robust to this assumption. We also checked that our findings are robust to switching to the model which Garcia-Cicco et al. (2010) and Miyamoto and Nguyen (2017) used (small open economy RBC).

of foreign debt than our function or Schmitt-Grohe and Uribe (2003). What is striking, is the much stronger reaction of the risk premium under the two former functions, which explains the remaining differences. When households face a sharply rising premium they are less willing to smooth domestic shocks by borrowing from abroad. As a result the economy becomes more autarcic.

The answer to the second question is less straightforward, but a plausible hypothesis can be formulated. Both Garcia-Cicco et al. (2010) and Miyamoto and Nguyen (2017) estimate their models with macroeconomic data only i.e. without observing the risk premium. This is understandable given their long data sets, for which time series on bond yields would be unavailable. But the imminent consequence is that the coefficient of the risk premium function adjusts so, as to provide a good fit to the macroeconomic series, ignoring what the data has to say about the link between debt and risk. For instance, as can be observed on Figure 7, under the Garcia-Cicco et al. (2010) calibration a 1 percentage point increase in foreign debt-to-GDP ratio implies a premium higher by 60 basis points, which seems a lot. Most possibly the coefficient captures all impediments to capital flows, including *de iure* restrictions and sudden stop events found in the data.

5   Conclusions

This paper explores the non-linear relationship between the country risk premium and its net foreign asset position. This non-linearity is of particular importance since it may lead countries into debt traps. If risk premia initially increase slowly with worsening NFA positions and then suddenly jump the country may not be able to serve its foreign debt anymore. Moreover, the resulting sharp increase in financing costs may cause an economic recession. Greece could serve as a recent example of such unpleasant developments.

We estimate a non-linear panel model based on data from 41 advanced and emerging economies. Our specification is flexible enough to allow for a wide range of non-linearities. The data favors a non-linear relationship with a relatively fast transition between low and high elasticity regimes. For positive and mildly negative NFA positions the risk premium elasticity is only slightly negative. However, once NFA worsens further the elasticity decreases substantially. The strongest impact is experienced for NFA below approximately -70% to -75% of annual GDP.

An important by-product of our estimation is a risk premium - foreign debt relationships that can be applied in DSGE models. Such a relationship has for a long time constituted an important ingredient of small open economy DSGE models. However, its calibration was supposed to provide model stability rather than reflect the elasticities found in the data. Our paper offers an appropriate calibration.

Moreover, we show on the basis of a standard two-economy DSGE model that taking into account the non-linear risk premium - NFA relationship has important consequences for such models. First, it allows to take into account diverging rates of time preference in a way that is consistent with a well parametrized steady state. Second, we show that model dynamics differ significantly depending on the steady state NFA position. In particular, the higher steady state debt the stronger the impact of shocks on the domestic economy and the weaker on net exports. Finally, we show that and explain why the DSGE model with our estimated risk premium specification differs from models with calibrations/ estimations known from the literature.

References

Adolfson, Malin, Stefan Laseen, Jesper Linde, and Mattias Villani (2007) 'Bayesian estimation of an open economy DSGE model with incomplete pass-through.' *Journal of International Economics* 72(2), 481–511

Baldacci, Emanuele, and Manmohan S. Kumar (2010) 'Fiscal Deficits, Public Debt, and Sovereign Bond Yields.' IMF Working Papers 10/184, International Monetary Fund, August

Bellas, Dimitri, Michael G Papaioannou, and Iva Petrova (2010) 'Determinants of Emerging Market Sovereign Bond Spreads: Fundamentals vs Financial Stress.' IMF Working Papers 10/281, International Monetary Fund, December

Benczur, Peter, and Istvan Konya (2015) 'Interest Premium, Sudden Stop, and Adjustment in a Small Open Economy.' IEHAS Discussion Papers 1505, Institute of Economics, Centre for Economic and Regional Studies, Hungarian Academy of Sciences, January

Christoffel, Kai, Günter Coenen, and Anders Warne (2008) 'The New Area-Wide Model of the euro area: a micro-founded open-economy model for forecasting and policy analysis.' Working Paper Series 0944, European Central Bank, October

Ciocchini, Francisco, Erik Durbin, and David T. C. Ng (2003) 'Does corruption increase emerging market bond spreads?' *Journal of Economics and Business* 55(5-6), 503–528

Dohmen, Thomas, Benjamin Enke, Armin Falk, David Huffman, and Uwe Sunde (2016) 'Patience and the Wealth of Nations.' Working Papers 2016-012, Human Capital and Economic Opportunity Working Group, April

Escribano, Álvaro, and Oscar Jordá (2001) 'Testing nonlinearity: Decision rules for selecting between logistic and exponential STAR models.' *Spanish Economic Review* 3(3), 193–209

Fagan, Gabriel, and Vitor Gaspar (2007) 'Adjusting to the euro.' Working Paper Series 716, European Central Bank

Falk, Armin, Anke Becker, Thomas Dohmen, Benjamin Enke, David B. Huffman, and Uwe Sunde (2015) 'The Nature and Predictive Power of Preferences: Global Evidence.' IZA Discussion Papers 9504, Institute for the Study of Labor (IZA), November

Ferrucci, Gianluigi (2003) 'Empirical determinants of emerging market economies' sovereign bond spreads.' Bank of England Working Papers 205, Bank of England, November

Fouejieu, Armand, and Scott Roger (2013) 'Inflation Targeting and Country Risk: An Empirical Investigation.' IMF Working Papers 13/21, International Monetary Fund, January

Garcia-Cicco, Javier, Roberto Pancrazi, and Martin Uribe (2010) 'Real Business Cycles in Emerging Countries?' *American Economic Review* 100(5), 2510–31

González, Andrés, Timo Teräsvirta, and Dick van Dijk (2005) 'Panel Smooth Transition Regression Models.' SSE/EFI Working Paper Series in Economics and Finance 604, Stockholm School of Economics, August

Granger, Clive W. J., and Timo Teräsvirta (1993) *Modelling Non-Linear Economic Relationships* (Oxford University Press, Oxford)

Gumus, Inci (2013) 'Debt denomination and default risk in emerging markets.' *Macroeconomic Dynamics* 17(5), 1070–1095

Hansen, Bruce E (1996) 'Inference When a Nuisance Parameter Is Not Identified under the Null Hypothesis.' *Econometrica* 64(2), 413–30

IMF (2013) 'External balance assessment (EBA) methodology: technical background.' Background paper, International Monetary Fund

Justiniano, Alejandro, and Bruce Preston (2010) 'Monetary policy and uncertainty in an empirical small open-economy model.' *Journal of Applied Econometrics* 25(1), 93–128

Lane, Philip R., and Gian Maria Milesi-Ferretti (2001) 'The external wealth of nations: measures of foreign assets and liabilities for industrial and developing countries.' *Journal of International Economics* 55(2), 263–294

Luukkonen, Ritva, Pentti Saikkonen, and Timo Teräsvirta (1988) 'Testing linearity against smooth transition autoregressive models.' *Biometrika* 75(3), 491–499

Miyamoto, Wataru, and Thuy Lan Nguyen (2017) 'Business Cycles in Small, Open Economies: Evidence from Panel Data Between 1900 and 2013.' *Journal of International Economics, Forthcoming*

Schmitt-Grohe, Stephanie, and Martin Uribe (2003) 'Closing small open economy models.' *Journal of International Economics* 61(1), 163–185

Smets, Frank, and Raf Wouters (2005) 'Comparing shocks and frictions in US and euro area business cycles: a Bayesian DSGE Approach.' *Journal of Applied Econometrics* 20(2), 161–183

Teräsvirta, Timo (1994) 'Specification, estimation, and evaluation of smooth transition autoregressive models.' *Journal of the American Statistical Association* 89(425), 208–218

Tables and Figures

Table 1: List of countries included

Country	Sample	Classification	Country	Sample	Classification
Australia	1991-2014	AE	Korea	1995-2014	AE
Austria	1991-2013	AE	Malaysia	1994-2014	EM
Belgium	1991-2014	AE	Mexico	1997-2014	EM
Brazil	2011-2014	EM	Morocco	1999-2012	EM
Canada	1991-2014	AE	Netherlands	1991-2014	AE
Chile	2006-2013	EM	New Zealand	1991-2013	AE
China	2007-2014	EM	Norway	1991-2013	AE
Colombia	2003-2013	EM	Pakistan	1995-2013	EM
Costa Rica	2013-2014	EM	Philippines	1995-2007	EM
Czech Republic	2001-2013	AE	Poland	2002-2014	EM
Denmark	1993-2013	AE	Portugal	1991-2013	AE
Finland	1991-2013	AE	Russia	2006-2011	EM
France	1991-2014	AE	South Africa	2001-2014	EM
Germany	1993-2014	AE	Spain	1991-2014	AE
Greece	1994-2013	AE	Sweden	1994-2014	AE
Hungary	2002-2013	EM	Switzerland	1991-2014	AE
India	2000-2014	EM	Thailand	1997-2014	EM
Indonesia	2004-2014	EM	Turkey	2007-2014	EM
Ireland	1996-2013	AE	United Kingdom	1991-2014	AE
Italy	1991-2014	AE	Uruguay	2004-2013	EM
Japan	1991-2014	AE			

Note: The studied economies are classified as emerging markets (EM) or advanced economies (AE).

Table 2: Estimation results - linear model

	(1)	(2)
	FE-OLS	FE-IV
NFA	-1.127***	-1.129**
	(0.376)	(0.376)
INF DIF	0.517***	0.519***
	(0.055)	(0.054)
EXRATE VOL	0.137***	0.114**
	(0.043)	(0.044)
GG DEBT	0.022***	0.022***
	(0.006)	(0.006)
GG BALANCE	-0.032	-0.032
	(0.021)	(0.021)
GDP PER CAP	-7.974***	-7.992***
	(2.044)	(2.047)
YIELD SPREAD	-0.170***	-0.169***
	(0.058)	(0.058)
GS IND	0.098	0.105
	(0.066)	(0.066)
const	-5.706	-6.284
	(6.547)	(6.600)
R2	0.750	0.750
Adj R2	0.732	0.732
Obs	693	693
J-test (p-value)	-	0.267

Note: The model in column 1 is the fixed effects model estimated with OLS. The model in column 2 has been estimated using IV estimator. We instrumented variable EXRATE VOL with its first differences and the squares of the first differences as well as VIX variable. The detailed description of control variables: see Section 2. White period standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 3: Linearity tests

Test	(1) FE-OLS Wald	(2) FE-OLS WaldF	(3) FE-IV Wald	(4) FE-IV WaldF
$H_0 : \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = 0$	11.210**	2.803**	11.231**	2.808**
	(0.0243)	(0.0251)	(0.0241)	(0.0249)
$H_{0L} : \lambda_1 = \lambda_3 = 0$	4.702*	2.351*	4.698*	2.349*
	(0.0953)	(0.0961)	(0.0955)	(0.0963)
$H_{0E} : \lambda_2 = \lambda_4 = 0$	3.841	1.921	3.832	1.916
	(0.1465)	(0.1474)	(0.1472)	(0.1481)

Note: The numbers in the table are the values of the test statistics to verify the following hypotheses: the hypothesis of linearity against the general PSTR non-linearity (H_0), the hypothesis of linearity against the PSTR model with logistic transition function (H_{0L}), the hypothesis of linearity against the PSTR model with exponential transition function (H_{0E}). The auxiliary regression is the equation (5). The numbers in columns 1 and 2 refer to the fixed effects model estimated with OLS while the numbers in columns 3 and 4 refer to fixed effects model estimated with IV estimator. We instrumented variable EXRATE VOL with its first differences, the squares of the first differences and VIX variable. We used Wald Chi2- and F-type test statistics. The detailed description of control variables: see Section 2. Wald test p-values in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 4: Estimation results - PSTR model with logistic transition function

	(1)	(2)	(3)	(4)	(5)	(6)
	FE-OLS	FE-IV	FE-TD-OLS	FE-TD-IV	FE-EM-OLS	FE-EM-IV
NFA (δ_1) - regime I	-2.008***	-2.011***	-2.118***	-2.112***	-2.011***	-2.017***
	(0.717)	(0.722)	(0.615)	(0.622)	(0.713)	(0.724)
NFA (δ_2)	1.846**	1.846**	2.285***	2.310***	1.867***	1.866**
	(0.726)	(0.731)	(0.625)	(0.631)	(0.719)	(0.732)
NFA ($\delta_1 + \delta_2$) - regime II	-0.161	-0.165	0.167	0.198	-0.145	-0.151
	-	-	-	-	-	-
Transition parameter (γ)	200.08	200.70	1283.48	1282.62	225.33	206.23
	(434.98)	(424.86)	(4887.78)	(9902.28)	(466.34)	(456.86)
Threshold parameter (c)	-0.742***	-0.742***	-0.721***	-0.721***	-0.697***	-0.701***
	(0.012)	(0.012)	(0.002)	(0.005)	(0.007)	(0.004)
AE dummy	-	-	-	-	-0.044***	-0.042***
					(0.015)	(0.013)
INF DIF	0.519***	0.523***	0.513***	0.514***	0.520***	0.525***
	(0.070)	(0.068)	(0.068)	(0.067)	(0.070)	(0.068)
EXRATE VOL	0.137***	0.106***	0.137***	0.073*	0.141***	0.106***
	(0.047)	(0.038)	(0.040)	(0.040)	(0.047)	(0.038)
GG DEBT	0.017**	0.016**	0.015***	0.015***	0.017**	0.016**
	(0.008)	(0.008)	(0.006)	(0.006)	(0.008)	(0.008)
GG BALANCE	-0.036	-0.036	-0.015	-0.015	-0.036	-0.037
	(0.028)	(0.029)	(0.032)	(0.033)	(0.028)	(0.029)
GDP PER CAP	-8.254***	-8.277***	-10.586***	-10.56***	-8.402***	-8.409***
	(3.136)	(3.198)	(3.425)	(3.475)	(3.142)	(3.211)
YIELD SPREAD	-0.164**	-0.163**	-0.007	0.039	-0.161**	-0.159**
	(0.069)	(0.070)	(0.434)	(0.442)	(0.069)	(0.070)
GS IND	0.105	0.114	0.496	0.574	0.109	0.118
	(0.073)	(0.075)	(0.463)	(0.472)	(0.073)	(0.075)
R2	0.359	0.353	0.493	0.487	0.359	0.353
Adj R2	0.349	0.344	0.468	0.461	0.349	0.343
Obs	693	693	693	693	693	693

Note: The numbers in columns 1 and 2 refer to PSTR model with exponential transition function with fixed effects. The model in column 1 has been estimated with OLS while the model in column 2 with IV estimator. The numbers in columns 3 and 4 stand for parameter estimates for the models with period dummies estimated respectively with OLS and IV method. The values in columns 5 and 6 refer to models, which allow for different threshold level for NFA position for emerging and advanced economies. This difference is captured by the AE dummy variable. The detailed description of control variables: see Section 2. HAC standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 5: Parameters of the risk premium function in DSGE models

ψ_1	ψ_2	ψ_3	ψ_4	ψ_5
0.0013	-0.0012	50	3	0.0001 for $d \ll 3$
				0.0013 for $d \gg 3$

Table 6: Calibration of the DSGE model

Parameter	Value	Description
β, β^*	0.9975	Discount factor
h, h^*	0.75	External habit
σ, σ^*	2	Inverse of intertemporal elasticity of substitution
φ, φ^*	2	Inverse of Frisch elasticity of labor supply
μ, μ^*	1.33	Parameter of final good aggregator
μ_H, μ_F, μ_H^*, μ_F^*	1.2	Parameters of home and foreign good aggregator
θ_H, θ_F, θ_H^*, θ_F^*	0.75	Calvo parameters
$1 - \eta$	0.3	Import share in the domestic economy
α, α^*	0.33	Capital share
ω	0.01	Size of domestic economy
γ_R, γ_R^*	0.75	Autoregression in Taylor rule
γ_π, γ_π^*	2	Response to inflation in Taylor rule
γ_y, γ_y^*	0.125	Response to output in Taylor rule
ρ_u, ρ_u^*	0.75	Autoregression of preference shock
ρ_z, ρ_z^*	0.75	Autoregression of technology shock

Figure 1: Interest rate spreads and NFA positions
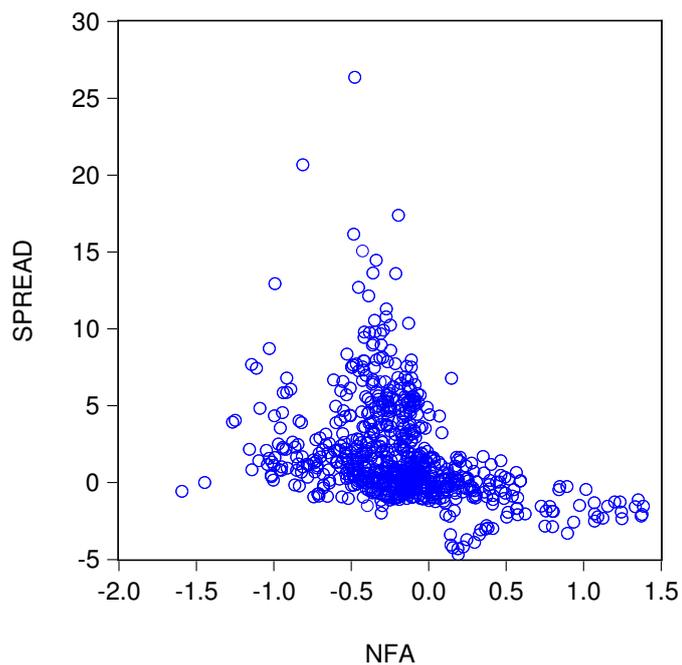
Figure 2: Examples of risk premium - NFA relationship with logistic transition function
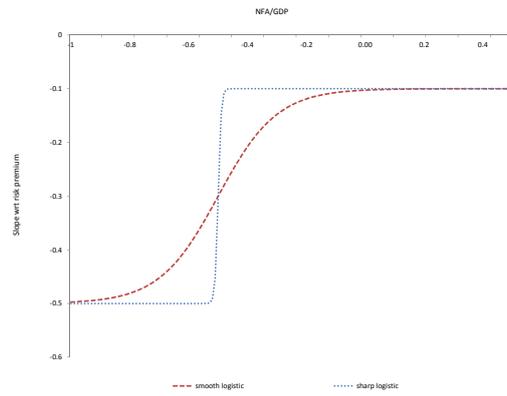

Figure 3: Examples of risk premium - NFA relationship with exponential transition function
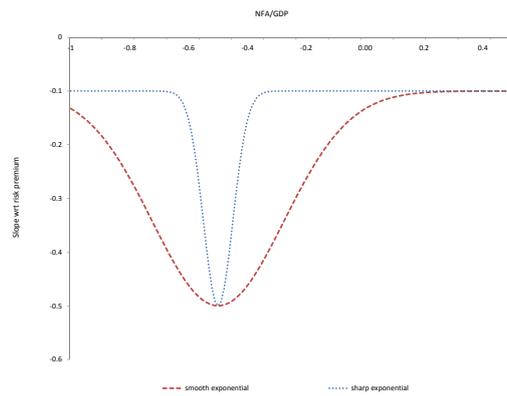
Figure 4: The estimated semi-elasticity of the risk premium with respect to the net foreign asset to GDP ratio
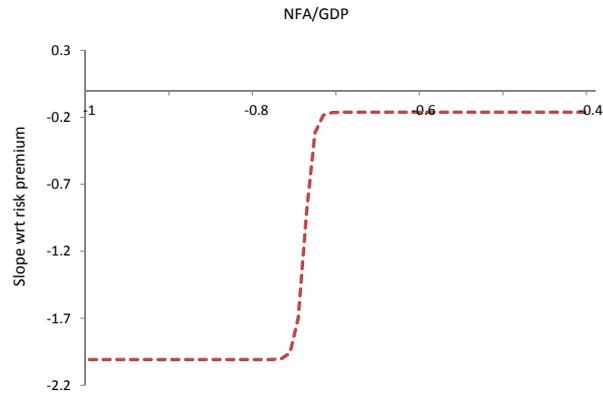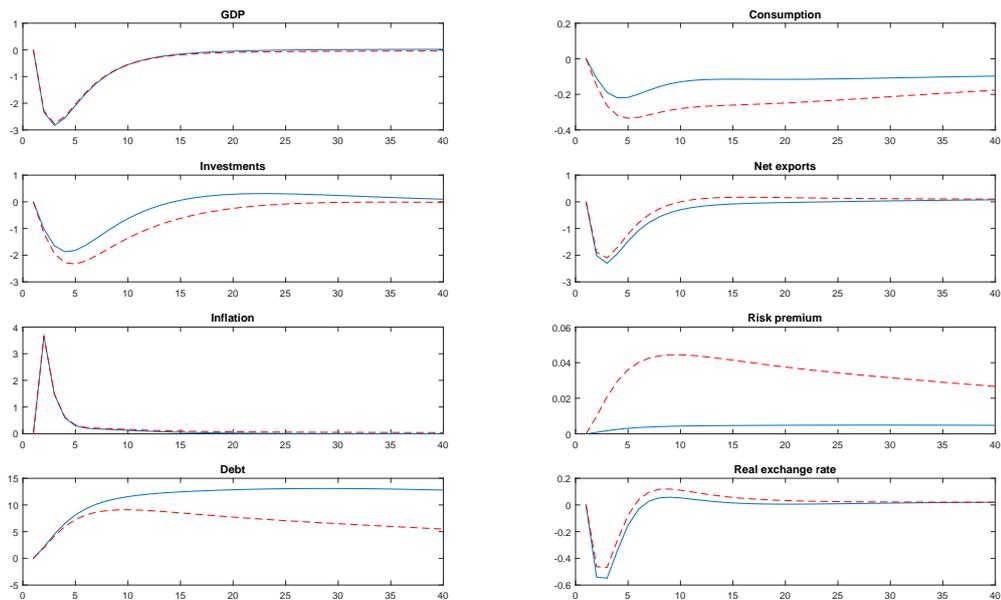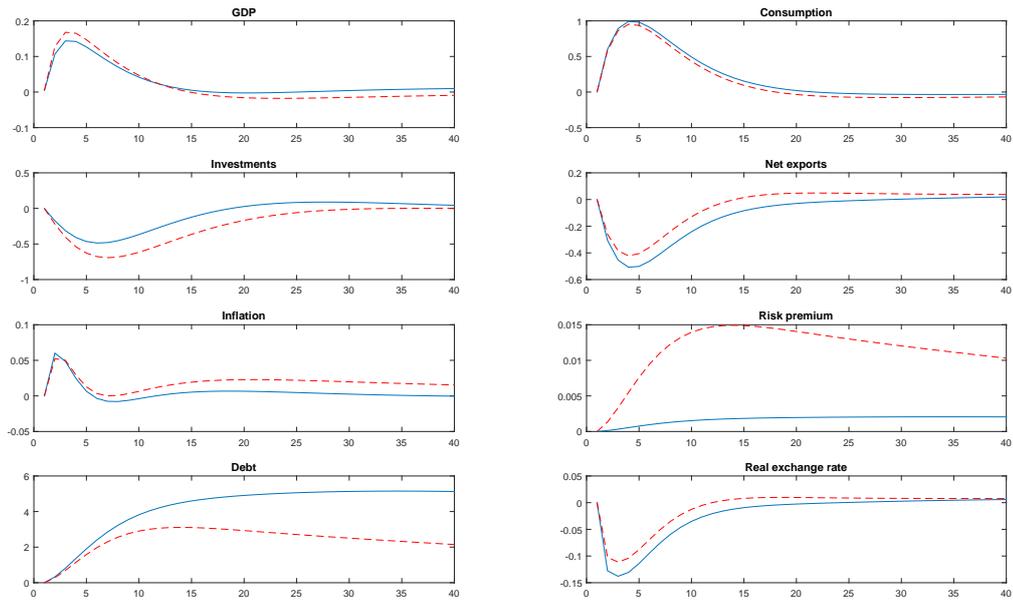

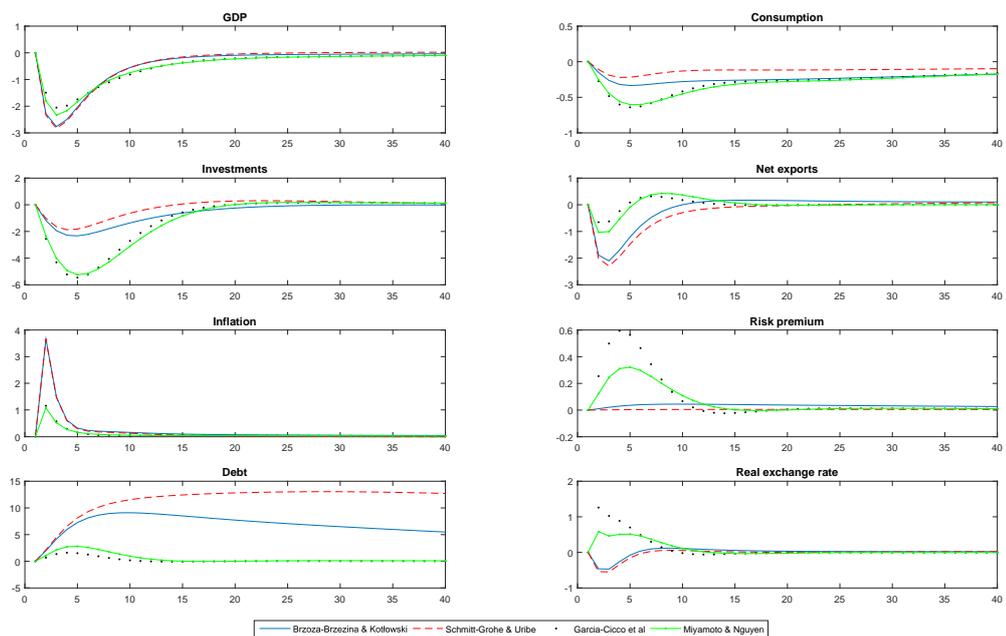Figure 5: Impulse responses to productivity shock

Note: blue, solid line - low debt to GDP ratio ($\psi_5 = 0.0001$). Red, dashed line - high debt to GDP ratio ($\psi_5 = 0.0013$). All variables presented as deviation from steady state. GDP, consumption, investments and real exchange rate expressed in percent. Inflation and risk premium in annualized percentage points. Debt and net exports in percent of GDP.

Figure 6: Impulse responses to preference shock

Note: blue, solid line - low debt to GDP ratio ($\psi_5 = 0.0001$). Red, dashed line - high debt to GDP ratio ($\psi_5 = 0.0013$). All variables presented as deviation from steady state. GDP, consumption, investments and real exchange rate expressed in percent. Inflation and risk premium in annualized percentage points. Debt and net exports in percent of GDP.

Figure 7: Impulse responses to productivity shock - comparison of different risk premium functions

Note: the figure presents impulse responses to productivity shocks resulting from assuming four different risk premium specifications: (i) this paper, (ii) Schmitt-Grohe and Uribe (2003), (iii) Garcia-Cicco et al. (2010) and (iv) Miyamoto and Nguyen (2017). All variables presented as deviation from steady state. GDP, consumption, investments and real exchange rate expressed in percent. Inflation and risk premium in annualized percentage points. Debt and net exports in percent of GDP.

Appendix: DSGE model

Below we present the details of the DSGE model. We show explicitly only problems of the domestic agents, problems of foreign agents are symmetric. Foreign variables are denoted with an asterix.

Households

There is an infinity of equal households which work n_t, consume c_t and accumulate domestic B_t and foreign B_t^* bonds remunerated at the central bank interest rates R_t and R_t^* respectively. Moreover, they own the capital stock k_t which is rented to firms at the rate R_t^K and depreciates at the rate δ. A representative household ι maximizes lifetime utility:

$$maxU_t = E_t \sum_{i=0}^{\infty} \beta^i e^{\varepsilon_{u,t+i}} \left[\frac{(c_{t+i}(\iota) - hc_{t+i-1})^{1-\sigma}}{1 - \sigma} - A_n \frac{(n_{t+i}(\iota))^{1+\varphi}}{1 + \varphi} \right] \tag{A.1}$$

subject to a sequence of budget constraints:

$$P_t c_t(\iota) + P_t i_t(\iota) + B_t(\iota) + S_t B_t^*(\iota) = W_t n_t(\iota) + R_t^K k_t(\iota) + R_{t-1} B_{t-1}(\iota) + S_t \rho_{t-1} R_{t-1}^* B_{t-1}^*(\iota) + \Pi_t \tag{A.2}$$

and the law for capital accumulation

$$k_{t+1} = (1 - \delta)k_t + \left[1 - \Gamma \left(\frac{i_t}{i_{t-1}} \right) \right] i_t \tag{A.3}$$

where P_t, W_t, S_t, Π_t are, respectively the price of consumption goods, the nominal wage, the nominal exchange rate and dividends paid by imperfectly competitive intermediate goods producers. Further, i_t denotes investments and $\Gamma(\bullet)$ a quadratic investment adjustment cost. Moreover, β denotes the agents discount rate and A_n is the weight of labor in utility. The inverse of the intertemporal elasticity of substitution in consumption is denoted by σ and φ is the inverse Frisch elasticity of labor supply. Consumption is subject to external habit persistence h. We assume that the intertemporal preference shock $\varepsilon_{u,t}$ follows an AR(1) process with persistence ρ_u and standard deviation of innovations σ_u. The international risk premium ρ_t is assumed to follow (8).

We will not present all equilibrium conditions, only those referred to in the paper. The first is the Euler consumption equation:

$$\frac{\lambda_t}{P_t} = \beta E_t \frac{\lambda_{t+1}}{P_{t+1}} R_t \tag{A.4}$$

and the second the uncovered interest rate parity (UIP) condition:

$$E_t \frac{\lambda_{t+1}}{\pi_{t+1}} R_t = E_t \frac{q_{t+1} \lambda_{t+1} \rho_t R_t^*}{\pi_{t+1}^* q_t} \tag{A.5}$$

where $\frac{\lambda_t}{P_t}$ is the Lagrange multiplier on the budget constraint, $\pi_t \equiv \frac{P_t}{P_{t-1}}$ is inflation and $q_t \equiv \frac{S_t P_t^*}{P_t}$ the real exchange rate.

Producers

There are two types of firms: intermediate goods producers and final good producers. Perfectly competitive final good producers purchase intermediate domestic and foreign goods and produce a final good $\tilde{y}_t$ using the following technology

$$\tilde{y}_t = \left[\eta^{\frac{\mu-1}{\mu}} (y_{H,t})^{\frac{1}{\mu}} + (1-\eta)^{\frac{\mu-1}{\mu}} (y_{F,t})^{\frac{1}{\mu}} \right]^{\mu} \tag{A.6}$$

where η is the home bias and μ determines the elasticity of substitution between domestic and foreign goods while $y_{H,t} = \left(\int_0^1 y_{H,t}(j)^{\frac{1}{\mu_H}} dj \right)^{\mu_H}$ and $y_{F,t} = \left(\int_0^1 y_{F,t}(j)^{\frac{1}{\mu_F}} dj \right)^{\mu_F}$ are aggregates of domestic and foreign intermediate goods respectively. Parameters μ_H and μ_F determine the elasticities of substitution between their varieties.

Producers of intermediate goods act under monopolistic competition. They produce specific (differentiated) goods and sell them to final good producers at home and abroad. They solve the same cost minimization problem, however, have different pricing strategies for the domestic and foreign market. Local currency pricing is assumed, i.e. prices are sticky in the buyers currency. They produce using the following technology

$$y_{H,t}(j) + y_{H,t}^*(j) = e^{z_t} k_t^{\alpha}(j) n_t^{1-\alpha}(j) \tag{A.7}$$

where z_t denotes a productivity shock that follows an AR(1) process with persistence ρ_z and standard deviation of innovations σ_z. Intermediate goods producers set their prices according to the Calvo scheme. In each period, each producer j receives with probability $1 - \theta_H$ or $1 - \theta_H^*$ a signal to re-optimize her price on the domestic or foreign market respectively. She then maximizes:

$$\max_{\tilde{P}_{H,t}(j), \{y_{H,t}(j)\}_{s=0}^{\infty}} E_t \sum_s (\beta \theta_H)^s \lambda_{t+s} \left(\frac{\tilde{P}_{H,t}(j)}{P_{t+s}} - mc_{t+s} \right) y_{H,t+s}(j) \tag{A.8}$$

when producing for the domestic market, or

$$\max_{\tilde{P}^*_{H,t}(j),\{y^*_{H,t}(j)\}^\infty_{s=0}} E_t \sum_s (\beta\theta^*_H)^s \lambda_{t+s} \left(\frac{\tilde{P}^*_{H,t}(j)\, S_{t+s}}{P_{t+s}} - mc_{t+s} \right) y^*_{H,t+s}(j) \qquad \text{(A.9)}$$

when producing for the export market. When setting prices she faces downward sloping demand curves, that solve the problems of domestic and foreign final goods producers. In the equations above profits are evaluated according to the households (i.e. the owners) marginal utility of consumption, $\tilde{P}_{H,t}(j)$ and $\tilde{P}^*_{H,t}(j)$ are the new prices set on the domestic and foreign market by those firms that are allowed to change their price and mc_t is the real marginal cost.

Monetary policy and market clearing

The central bank follows a standard Taylor rule (variables without time indices denote steady state levels)

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\gamma_R} \left[\left(\frac{\pi_t}{\pi} \right)^{\gamma_\pi} \left(\frac{y_t}{y} \right)^{\gamma_y} \right]^{1-\gamma_R} \qquad \text{(A.10)}$$

where γ_R, γ_π and γ_y are parameters and $y_t \equiv y_{H,t} + \frac{1-\omega}{\omega} y^*_{H,t}$ denotes real GDP (ω is the size of the domestic economy).

The resource constraint is:

$$\tilde{y}_t = c_t + i_t \qquad \text{(A.11)}$$

and net foreign assets evolve following the balance of payments equation:

$$\omega P_{F,t} y_{F,t} + \omega S_t B^*_t = (1-\omega) S_t P^*_{H,t} y^*_{H,t} + \omega S_t B^*_{t-1} R_{t-1} \rho_{t-1} \qquad \text{(A.12)}$$

The foreign debt-to-GDP ratio is defined as $d_t \equiv -\frac{S_t B^*_t}{P_t y_t}$.