"Debt intolerance:" Threshold of level and composition*

Hideaki Matsuoka†

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Abstract

Fiscal vulnerabilities depend on both the level and composition of government debt. This paper investigates the threshold value of debt level and its composition to understand the non-linear behavior of the long-term interest rate by developing the novel approach: the panel smooth transition regression with the general logistic model (Generalized panel smooth transition regression). Our main finding is threefold: (i) The impact of the expected public debt on the interest rate would increase exponentially and significantly as the foreign private holdings ratio exceeds approximately 20 percent. Otherwise, strong home bias would mitigate the upward pressure of the increase in public debt on the interest rate. (ii) If the expected public debt-to-GDP ratio exceeds a certain level that depends on the funding source, the increase in foreign private holdings of government debt would cause a rise of long-term interest rates, offsetting the downward effect on long-term interest rates by expanding market liquidity. (iii) Out-of-sample forecast of our novel non-linear model is more accurate than those of previous methods. Consequently, the composition of government debt plays an important role in highly non-linear behavior of the long-term interest rate.

Key Words: *Generalized panel smooth transition regression, Expected public debt-to-GDP ratio, Foreign private investors, Long-term interest rate*

JEL Codes: E43,E62,H63

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†World Bank, E-mail address:hmatsuoka@worldbank.org Postal address: 1818 H Street NW, MC2-204, Washington DC, 20433 USA /TEL:+1-202-473-8009

"The experiences of foreign economies suggest that the relationship between debt and interest rates is complex and likely non-linear, with the influence of greater debt on interest rates rising as the debt-to-GDP ratio reaches a trajectory at which investors have concerns about its sustainability."

-Brainard (2017)

"The level of debt that is sustainable in an economy is not a constant. It can change over time and indeed has changed enormously over the last 150 years. The ratio of credit to GDP in the late Victorian British economy was under 20 percent. In the mid-twentieth century it was around 60 percent and by the early 1990s over 100 percent."

-Cunliffe (2019)

1. Introduction

As argued by Reinhart et al. (2003), fiscal vulnerabilities depend on both the level and composition of government debt. They describe the "debt intolerance" phenomenon, in which interest rates in developing economies can spike above the "tolerance ceiling", even though the debt levels could be considered manageable by advanced country standards. As shown in Figure 1 and 2, the long-term interest rates in advanced economies (AEs) have been lower than those in Emerging markets (EMs) although debt levels in AEs such as Japan, United Kingdom and the United State are much higher in EMs. While significant research has been devoted to estimate the marginal impact of public debt on long-term interest rates, there are different estimated impacts[1]. Hence, the composition for holdings of government bonds (foreign vs. domestic or official vs. private) as well as its level could be the determinant of long-term yields. This paper examines how the interaction between the funding source and the expected public debt affects the long-term interest rates.

Some maintain that foreign investors require higher risk premia than domestic ones when the government would likely repay domestic ones before foreign ones[2]. Azzimonti and Quadrini (2017) find the integration of financial markets increases the incentives to default by a given country not only because part of the defaulted is

[1]Please see Section 3.4 for the detail.

[2]This argument is based on the assumption that the government can default selectively on foreign investors. Erce and Mallucci (2018) find that selective defaults have existed and been frequent over the period 1980-2015. Since 1980 about two-thirds of the defaults have involved either foreign-law bonds or domestic-law bonds selectively. In contrast, Sturzenegger and Zettelmeyer (2008) conclude that with a few exceptions, domestic investors do not appear to have been treated systematically better than foreign investors between 1998 and 2005. Broner et al. (2014) argue that selective default can happen when the government can impose capital controls to make it easier to discriminate. On the other hand, Broner et al. (2010) show that secondary markets both reduce the probability of default on foreigners and make it difficult for the government to discriminate among creditors.

owned by foreigners, but also because the macroeconomic cost of a default is smaller when the defaulting country is financially integrated. Gros (2013) and Ichiue and Shimizu (2015) also argue that if domestic financial institutions have a large share of government bonds, any losses they might incur would be amplified by the damage these losses would cause to the broader financial system. To avoid this, governments would have a clear incentive to select the fiscal consolidation rather than undergo default.

Empirically, Dell'Erba et al. (2013) and Ichiue and Shimizu (2015) conclude that when an increase in debt is financed by foreign borrowing, the increase in the interest rate is greater than when the increase is financed domestically[3]. For more non-linearity, Brzoza-Brzezina and Kotlowski (2018) show that risk premia initially increase slowly with worsening the net financial assets positions and then suddenly jump, using the panel smooth transition regression (PSTR) developed by González et al. (2017). Similarly, Agca and Celasun (2012) show that the impact of domestic public debt on the syndicated loan yield spreads is not statistically significant whereas that of external public debt is significant.

On the other hand, Reinhart and Trebesch (2015) argue that an increase in the share of foreign investors is associated with lower long-term interest rates because these holdings supplement domestic saving in capital-scarce countries, especially in times of high global liquidity. Peiris (2013) describe that while domestic investors are typically buy-and-hold investors, foreign investors are more likely to trade. Some empirical studies support this downward effect (Arslanalp and Poghosyan (2016), Carvalho and Fidora (2015), Ebeke and Lu (2015) and Warnock and Warnock (2009)). From another angle, Azzimonti et al. (2014) illustrates that small countries which face a larger world market relative to their own economies perceive the interest rate as less sensitive to their own debt in a globalized world since both the demand and supply of government debt come out only from domestic investors and government but also from their foreign.

Although a large body of literature shows both positive and negative impacts from an increase in the share of foreign debt on government bond yields, the reconciliation of these opposite impacts has received less attention by investigating the threshold. To investigate such a threshold, the non-linear technique also has not been examined well beyond a few papers. Our work is closely related to Ebeke and Lu (2015) and Brzoza-

[3] Asonuma et al. (2015) also show that higher home bias mitigates the upward pressure of the increase in public debt on bond spreads, using three home bias indicators: (1) Banks' holding of domestic sovereign claims / Banks' total assets, (2) Banks' holding of domestic sovereign claims / Banks' holding of sovereign claims and (3) Banks' holding of domestic sovereign claims / Public debt of sovereign. Their result is line with the fiscal crisis model of Sakuragawa and Sakuragawa (2016) that explain why domestic investors do not require a risk premium against large outstanding debt when there is a strong home bias in the asset portfolio of domestic bondholders because these investors turn out to have no access to any assets that hedge fiscal risk.

Brzezina and Kotlowski (2018). Ebeke and Lu (2015) show that in emerging markets an increase in the share of foreign holdings has a negative impact on yield but if either the lagged external debt-to-GDP ratio exceeds 90 percent or the lagged short-term debt-to-GDP ratio exceeds 21.5 percent, the corresponding impacts turn positive. Brzoza-Brzezina and Kotlowski (2018) find that the country's risk premium is large significantly as the net financial assets position is below approximately 70-75 percent of GDP.

This paper contributes to two strands of the literature, extending and complimenting Ebeke and Lu (2015) and Brzoza-Brzezina and Kotlowski (2018). First, an important methodological contribution is to develop the generalized panel smooth transition regression (GPSTR) by combining two approaches: the panel smooth transition regression (PSTR) and the general logistic model (GLM). Ebeke and Lu (2015) and Brzoza-Brzezina and Kotlowski (2018) employ the interaction-term model and PSTR model, respectively[4]. The most different point between GPSTR and the previous methods is that GPSTR can investigate the potential point asymmetry whereas the interaction-term model PSTR model exhibit point symmetry. As the impact of the increase in expected public debts on the interest rate is possible to be highly non-linear, it has to be econometrically investigated. We evaluate the performance of GPSTR by comparing the out-of-sample forecast error with those of other methods previous studies employed.

Second, we estimate two types of threshold values simultaneously to address the following questions :

(i) *Debt level change* : What is the threshold at which the share of foreign investors triggers a surge in government bond yields through the increase in the public debt?

(ii) *Debt composition change*: What is the threshold at which the level of public debt triggers a surge in government bond yields through the increase in the share of private foreign investors?

Ebeke and Lu (2015) and Brzoza-Brzezina and Kotlowski (2018) investigate only one kind of threshold but we do two types of threshold values simultaneously[5].

The remainder of this paper is organized as follows. Section 2 examines non-linear models: the interaction

[4]The motivation of Brzoza-Brzezina and Kotlowski (2018) to employ PSTR model is that the dynamic stochastic general equilibrium (DSGE) literature such as Schmitt-Grohe and Uribe (2003), Adolfson et al. (2007) and García-Cicco et al. (2010) assumes a nonlinear (e.g,, exponential) relationship between risk premia and foreign debt. As these DSGE studies don't assume that the government has the public debt, their country risk premium does not necessarily mean the sovereign risk premium. However, as Brzoza-Brzezina and Kotlowski (2018) use the difference between a country's long-term interest rate and the rate for the United States as a proxy variable for the measure of the country risk premium and PSTR model, it is most closely related to our study.

[5]These two previous studies use the actual debt data whereas we use a wide range of forecast data to omit any other effects of current economic condition on the interest rates as well as consider the forward looking behavior for the financial markets.

term model, PSTR and GPSTR model to explore the threshold values, using forecast data that includes 11 Advanced Economies(AEs) and 14 Emerging Markets(EMs). Section 3 shows the baseline estimation results, the model evaluation , and comparison with other studies. The conclusion is provided in Section 4.

2. Empirical strategy and data

We study determinants of local currency bond yields due to the fact that they are held by both domestic and foreign investors whereas the foreign currency bonds can be assumed to be held by only foreign investors. The price of local currency bonds would reflect the different behaviors of domestic and foreign investors. To investigate how the interaction between the funding source and the expected public debt affects the long-term interest rates, we examine three models below: (i) Interaction term model (IT), (ii) Panel Smooth Transition Regression (PSTR) and (iii) Generalized Panel Smooth Transition Regression (GPSTR).

(i) Interaction term model is the simple specification with the interaction term between the share of foreign private investors and the expected public debt. (ii) Panel Smooth Transition Regression (PSTR) is developed by González et al. (2017) and Fok et al. (2005). PSTR includes the standard logistic function that exhibits point symmetry with one slope parameter and one location parameter. Brzoza-Brzezina and Kotlowski (2018) is relevant to our empirical strategy because they employ the PSTR model to examine a nonlinear relationship between a country's risk premium and the net financial assets. (iii) In order to grasp the potential point asymmetry, this paper develops the generalized panel smooth transition regression (GPSTR) by replacing the standard logistic function employed by González et al. (2017) with GLM suggested by Stukel (1988).

2.1 Interaction Term (IT)

We start to employ the simple specification with the interaction term between the share of foreign private investors and the expected public debt as follows:

$$\mathbb{E}_t L_{i,t+n} = \alpha_i + \beta_0 \mathbb{E}_t Debt_{i,t+n} + \beta_1 \mathbb{E}_t Debt_{i,t+n} \cdot fp_{i,t-1} + \delta fp_{i,t-1} + \phi \mathbf{z_{i,t}} + \varepsilon_{i,t} \tag{1}$$

where a country $i = 1,\ldots, N$ at a time $t = 1,\ldots, T$,$\mathbb{E}_t L_{i,t+n}$ is the $n-$year-ahead forward long-term interest rate, $\mathbb{E}_t Debt_{i,t+n}$ is the n-year-ahead projection for the public debt (percent of GDP), $fp_{i,t-1}$ is lagged share of

private foreign investors and $\mathbf{z_{it}}$ describes control variables[6]. We analyze the effect of forward-looking projections of public debt on the forward interest rates to omit any effects of current economic conditions. As discussed by Engen and Hubbard (2005), Ichiue and Shimizu (2015) and Laubach (2009), when the deterioration of fiscal conditions and the decrease in interest due to the expected accommodative monetary policy occur simultaneously during a recession, the upward effect of fiscal deterioration on the long-term interest rates could be underestimated even if we control for other variables. In addition, the government bond yield is influenced by forward-looking variables. β_1 is expected to be larger than β_0 : domestic investors may not require a risk premium against large debt when there is a strong home bias without any other assets hedging fiscal risk. δ is expected to be negative: while domestic investors are typically buy-and-hold investors, foreign investors are more likely to trade. It could be supportive of increased market liquidity.

2.2 PSTR and GPSTR

Panel Smooth Transition Regression (PSTR) developed by González et al. (2017) and Fok et al. (2005) can be used to allow for a continuum of regimes, each one being characterized by a different value of the transition variable. Replacing $\mathbb{E}_t Debt_{i,t+n} fp_{i,t-1}$ in the interaction term model (1) with $\mathbb{E}_t Debt_{i,t+n} g(fp_{i,t-1};\gamma_1,c)$ gives the PSTR model:

$$\mathbb{E}_t L_{i,t+n} = \alpha_i + \beta_0 \mathbb{E}_t Debt_{i,t+n} + \beta_1 \mathbb{E}_t Debt_{i,t+n} \cdot g(fp_{i,t-1};\gamma_1,c) + \delta fp_{i,t-1} + \phi \mathbf{z_{i,t}} + \varepsilon_{i,t} \tag{2}$$

where $g(fp_{i,t-1};\gamma_1,c)$ is the standard logistic function ($\frac{1}{1+\exp(-\gamma_1(fp_{i,t-1}-c))}, \gamma_1 > 0$) that depends on the threshold variable $fp_{i,t-1}$, the slope parameters r_1 and location parameters c [7].This standard logistic function $g(fp_{i,t-1};\gamma_1,c)$ exhibits point symmetry with one slope parameter r_1. In other words, regardless of whether the threshold variable is larger or smaller than the location c, the impact of the public debt of all regimes could be affected by one slope parameter r_1. To investigate potential point asymmetry, we introduce two slope parameters (γ_1 and γ_2), replacing the standard logistic function with the general logistic model suggested by Stukel (1988).

The generalized panel smooth transition regression (GPSTR) is as follows:

[6]We take a lagged value of foreign investors to avoid a simultaneity bias.

[7]When $r_1 \to \infty$, PSTR model reduces to the two-regime panel threshold model by Hansen (1999).

$$\mathbb{E}_t L_{i,t+n} = \alpha_i + \beta_0 \mathbb{E}_t Debt_{i,t+n} + \beta_1 \mathbb{E}_t Debt_{i,t+n} \cdot g(fp_{i,t-1}; \gamma_1, \gamma_2, c) + \delta fp_{i,t-1} + \phi \mathbf{z_{i,t}} + \varepsilon_{i,t} \tag{3}$$

Following Stukel (1988), the general logistic model (GLM), $g(fp_{i,t-1}; \gamma_1, \gamma_2, c)$ is defined as follows:

$$g(fp_{i,t-1}; \gamma_1, \gamma_2, c) = \frac{\exp(h(fp_{i,t-1}; \gamma_1, \gamma_2, c))}{1 + \exp(h(fp_{i,t-1}; \gamma_1, \gamma_2, c))} \tag{4}$$

For $fp_{i,t-1} - c \leqslant 0$,

$$h(fp_{i,t-1}; \gamma_1, c) = \begin{cases} \gamma_1^{-1}(\log(1 - \gamma_1 |fp_{i,t-1} - c|)) & \gamma_1 < 0 \\ 0 & \gamma_1 = 0 \\ -\gamma_1^{-1}(\exp(\gamma_1 |fp_{i,t-1} - c|) - 1) & \gamma_1 > 0 \end{cases} \tag{5}$$

For $fp_{i,t-1} - c \geqslant 0$,

$$h(fp_{i,t-1}; \gamma_2, c) = \begin{cases} -\gamma_2^{-1}(\log(1 - \gamma_2 |fp_{i,t-1} - c|)) & \gamma_2 < 0 \\ 0 & \gamma_2 = 0 \\ \gamma_2^{-1}(\exp(\gamma_2 |fp_{i,t-1} - c|) - 1) & \gamma_2 > 0 \end{cases} \tag{6}$$

The transition functions $g(fp_{i,t-1}; \gamma_1, \gamma_2, c)$ depend on the lagged share of private foreign investors $fp_{i,t-1}$, the slope parameters r_1 ,r_2 and location parameters c. Figure 4 shows one example for the GLM $g(fp_{i,t-1}; \gamma_1, \gamma_2, c)$. The estimation of the parameters of the GPSTR model consists in eliminating the individual effects α_i by removing individual-specific means and then in applying non-linear least squares to the transformed model. The matrix of transformed explanatory variables is

$$x^*(\gamma_1, \gamma_2, c) = \left[\widetilde{\mathbb{E}_t Debt_{i,t+n}} : \widetilde{G_{i,t+n}} : \widetilde{fp_{i,t-1}} : \widetilde{\mathbf{z_{i,t}}}\right]' \tag{7}$$

where $\widetilde{\mathbb{E}_t L_{i,t+n}} = \mathbb{E}_t L_{i,t+n} - \overline{L_i}$, $\widetilde{\mathbb{E}_t Debt_{i,t+n}} = \mathbb{E}_t Debt_{i,t+n} - \overline{Debt_i}$, $\widetilde{fp_{i,t-1}} = fp_{i,t-1} - \overline{fp_i}$ and $\widetilde{\mathbf{z_{i,t}}} = \mathbf{z_{i,t}} - \overline{\mathbf{z_i}}$. $\widetilde{G_{i,t+n}}(\gamma_1, \gamma_2, c) = \widetilde{\mathbb{E}_t Debt_{i,t+n}} \cdot g(fp_{i,t-1}; \gamma_1, \gamma_2, c) - \frac{1}{T}\sum_{t=1}^{T} \mathbb{E}_t Debt_{i,t+n} \cdot g(fp_{i,t-1}; \gamma_1, \gamma_2, c)$ is the transformed explanatory variables in the second regime that depends on the parameters and the transition function. Given a couple (γ_1, γ_2, c), the parameters can be estimated by ordinary least squares, which yields:

$$\widehat{\Psi}(\gamma_1,\gamma_2,c) = \left[\sum_{i=1}^{N}\sum_{t=1}^{T} x^*_{i,t}(\gamma_1,\gamma_2,c)x^*_{i,t}(\gamma_1,\gamma_2,c)'\right]^{-1}\left[\sum_{i=1}^{N}\sum_{t=1}^{T} x^*_{i,t}(\gamma_1,\gamma_2,c)\widetilde{\mathbb{E}_t L_{i,t+n}}\right] \tag{8}$$

where$\widehat{\Psi}(\gamma_1,\gamma_2,c)$ is conditional to the values(γ_1,γ_2,c). For the next step, by increasing the number of combinations for(γ_1,γ_2,c), the parameters of the transition function γ_1 ,γ_2 and c are estimated by non-linear least squares :

$$(\hat{\gamma}_1,\hat{\gamma}_2,\widehat{c}) = \underset{\{\gamma_1,\gamma_2,c\}}{ArgMin}\sum_{i=1}^{N}\sum_{t=1}^{T}\left[\widetilde{\mathbb{E}_t L_{i,t+n}} - \widehat{\Psi}'(\gamma_1,\gamma_2,c)x^*(\gamma_1,\gamma_2,c)\right] \tag{9}$$

Consequently , $(\hat{\beta}_0 : \hat{\beta}_1 : \widehat{\delta} : \widehat{\phi})' = \widehat{\Psi}(\hat{\gamma}_1,\hat{\gamma}_2,\widehat{c})$.

The practical computation follows two steps.

- Step1. The initial values can be obtained by starting a grid search across the parameters γ_1 ,γ_2 and c where grid points are n_{γ_1}=20 n_{γ_2}=20 and n_c=30. Hence, the number of regressions is 12,000.
- Step2. We employ the Nelder–Mead simplex algorithm to find a local minimizer of the function non-linear least squares, using the initial values[8].

2.3 Threshold of level and composition

Using estimated parameters and solving $\frac{\partial \mathbb{E}_t L_{i,t+n}}{\partial \mathbb{E}_t Debt_{i,t+n}}$=0 and $\frac{\partial \mathbb{E}_t L_{i,t+n}}{\partial fp_{i,t-1}}$=0 can address the following two questions:

1. What is the threshold at which the share of foreign investors triggers a surge in government bond yields through the increase in the expected public debt?
2. What is the threshold at which the level of public debt triggers a surge in government bond yields through the increase in the share of foreign investors?

Table 1 shows threshold values of the marginal impact of the expected public debt ($\mathbb{E}_t Debt_{i,t+n}$) and the share of foreign private investors ($fp_{i,t-1}$) and on the interest rate in (1) Interaction term model and (2) GPSTR model.

The first column shows the share of foreign investors $fp_{i,t-1}$ that triggers a surge in government bond yields through the increase in the expected public debt. Those threshold values depend on the ratio of the first regime

[8]This algorithm uses a simplex of n + 1 points for n-dimensional vectors and discards the current worst point to reduce difference between the current best point and other points in simplex at each step in the iteration. See Lagarias et al. (1998) and Miranda and Fackler (2002) for the detail.

Table 1: Estimated threshold values of the impact of the increase in the share of foreign private investors ($fp_{i,t-1}$) and the expected public debt ($\mathbb{E}_t Debt_{i,t+n}$) on the interest rate

	$\frac{\partial \mathbb{E}_t L_{i,t+n}}{\partial \mathbb{E}_t Debt_{i,t+n}} = 0$	$\frac{\partial \mathbb{E}_t L_{i,t+n}}{\partial fp_{i,t-1}}$=0
(1) Interaction term	$fp_{i,t-1} = \frac{-\beta_0}{\beta_1}$	$\mathbb{E}_t Debt_{i,t+n} = \frac{-\delta}{\beta_1}$
(2) PSTR	$fp_{i,t-1} = \frac{-\beta_0}{\beta_1(fp_{i,t-1};\gamma_1,c)}$	$\mathbb{E}_t Debt_{i,t+n} = \frac{-\delta}{\beta_1\left\{\frac{\partial g(fp_{i,t-1};\gamma_1,,c)}{\partial fp_{i,t-1}}\right\}}$
(3) GPSTR	$fp_{i,t-1} = \frac{-\beta_0}{\beta_1(fp_{i,t-1};\gamma_1,\gamma_2,c)}$	$\mathbb{E}_t Debt_{i,t+n} = \frac{-\delta}{\beta_1\left\{\frac{\partial g(fp_{i,t-1};\gamma_1,\gamma_2,c)}{\partial fp_{i,t-1}}\right\}}$

parameter of the expected public debt (β_0) to the second regime parameter of the expected public debt (β_1, $\beta_1(fp_{i,t-1};\gamma_1,c)$ or $\beta_1(fp_{i,t-1};\gamma_1,\gamma_2,c)$).

The second shows the expected public debt $\mathbb{E}_t Debt_{i,t+n}$ that triggers a surge in government bond yields through the increase in the share of foreign investor[9]. If the denominator becomes larger and the numerator remains unchanged, the threshold of expected public debt becomes smaller. Intuitively, if investors are more sensitive to the expected public debt and require higher risk premium, the increase in foreign private holdings of government debt would cause a rise of long-term interest rates, offsetting the downward effect on long-term interest rates by expanding market liquidity, even if foreign investors can be supportive of increased market liquidity.

2.4 Data

2.4.1 Data coverage

Considering forecast data availability, we use the data of 25 countries: 11 Advanced Economies(AEs) and 14 Emerging Markets (EMs). AEs includes Australia, Canada, Czech Republic, Denmark, Japan, Korea, Norway, Sweden, Switzerland, United Kingdom, and the United States. EMs includes Bulgaria, Columbia, China, Hungary, India, Indonesia, Malaysia, Mexico, Peru, Philippines, Poland, Thailand, Turkey, and South Africa. The Euro area countries are omitted for the following reasons: As discussed by Ichiue and Shimizu (2015) and Wright (2011), this is because their term structures were highly correlated with those of Germany from the introduction of the euro. Therefore, it would be difficult to identify how much long-term interest rates in the Euro area have reflected the fundamentals of these countries. In connection with this, the share of foreign private investors in Euro area has been quite higher than others (Arslanalp and Tsuda (2014a)). In the Euro

[9]See Appendix A.2 for derivatives of the transition function $g(fp_{i,t-1};\gamma_1,\gamma_2,c)$.

Area, 0 percent risk weight has been a main driver of banks' holdings of foreign debt securities denominated in local currency due to the capital regulation by Basel. Bonner (2016) show capital regulation encourages banks to substitute other bonds with government bonds. Because of this regulatory impact, the impact of the foreign investors on the interest rates for Euro area could be different from other countries. Hence, the Euro area countries are omitted[10].

2.4.2 Forward interest rates

As discussed above, we use forward interest rates instead of current bond yields as a dependent variable. According to Shiller et al. (1983), the n -to-$m+n$ -year forward nominal interest rate $\mathbb{E}_t L^m_{i,t+n}$ is implied from the year-end $n-$ and $m+n-$year zero-coupon interest rates as follows:

$$\mathbb{E}_t L^m_{i,t+n} = \frac{(m+n)L^{m+n}_{i,t} - nL^n_{i,t}}{m} \tag{10}$$

Following Ichiue and Shimizu (2015), we employ the 5-to-10-year forward real interest as the dependent variable[11].

2.4.3 Expected public debt

We employ projections of government gross public debt to-GDP-ratio $\mathbb{E}_t Debt_{i,t+n}$ by the IMF *World Economic Outlook*, *Article IV Consultations*, OECD *Economic Outlook*, European Commission (EC) *European Economic Forecast*, and Economist Intelligence Unit (EIU). Following Gruber and Kamin (2012) and Ichiue and Shimizu (2015), we use the 2 year ahead projections of government gross public debt to-GDP-ratio as independent variables[12]. Since IMF *World Economic Outlook* have released its public debt projections for most countries twice a year, we use bi-annual data. However, as OECD, EC and IMF *Article IV Consultations* had made the 2 year ahead projections once a year over the years, we interpolate the same projections to construct bi-annual data.

[10] Brzoza-Brzezina and Kotlowski (2018) employing PSTR model also use the data in AEs and EMs. However, they use actual data, not forecast data

[11] Zero-coupon interest rate can be obtained from Bloomberg. To deflate the nominal interest rate into real interest rate, we use 2 year ahead projections of inflation $\mathbb{E}_t \pi_{i,t+2}$ due to data availability.

[12] Moreover, real-time vintages of data could affect long-term interest rates because fiscal data has been revised largely (De Castro et al. (2013)).

2.4.4 Foreign private holdings ratio

We use the lagged share of private foreign investors $fp_{i,t-1}$ as the threshold variable and one independent variable. The composition of holdings of government bonds by residency of the holders (foreign vs. domestic) is drawn from Arslanalp and Tsuda (2014a) and Arslanalp and Tsuda (2014b). As we use the forward interest rates for government debt securities denominated in local currency, foreign private holdings ratio $fp_{i,t-1}$ is measured as foreign private holdings share of government debt securities denominated in local currency[13]. Figure 3 shows that the share of foreign private investors has increased substantially in emerging markets since the global financial crisis whereas the share of foreign private investors in advanced economies excluding the Euro Area has decreased. As the risk-taking behavior of investors amid low interest rates of advanced economies, "search-for-yield" could cause the share of private foreign investors increase in emerging markets[14].

2.4.5 Other control variables

A vector of control variables $\mathbf{z_{i,t}}$ includes several variables. First, we use the lagged domestic official sector holdings ratio $do_{i,t-1}$ as a control variable. Central banks in AEs have been important players in government bond markets, purchasing government bonds financed by the creation of central bank reserves through quantitative easing — which central banks implemented to put downward pressure on interest rates when policy rates were at or near zero. The portfolio balance channel operates when central bank bond purchases, which change the relative supply of assets held by the private sector, induce equilibrating changes in relative yields[15]. In the United States, Gagnon et al. (2011) show a cumulative decline in 10-year Treasury yields by about 91 basis points after announcements of quantitative easing. According to Joyce et al. (2011), the corresponding impacts in the United Kingdom are estimated to be 100 basis points.

Second, we add the lagged foreign official holdings ratio $fo_{i,t-1}$ using data from Arslanalp and Tsuda (2014a) and Arslanalp and Tsuda (2014b). For example, U.S. long-term interest rates remained low in the mid-2000s despite increases in the federal funds rate, a phenomenon Alan Greenspan labeled a "conundrum" (Greenspan (2005)). Bernanke (2005) hypothesized that a global saving glut – driven by net savings in Asia

[13] See Appendix A.3 for the composition data in detail.

[14] The recent development may be due to the financial market developments in emerging markets. Mendoza et al. (2009) conclude that the external imbalances across the United States, other industrial countries, and emerging economies can result from financial integration when countries differ in financial markets development.

[15] Christensen and Rudebusch (2012), D'Amico et al. (2012) and Joyce et al. (2017) provide further discussion.

and oil-exporting countries – lowered long-term interest rates through an accumulation of foreign exchange reserves. In the U.S, Warnock and Warnock (2009) show that a 12-month total of foreign flows of one percentage point of GDP is associated with a 40 basis point reduction. Beltran et al. (2013) find that a 10 percentage point increase in foreign official flows into and out of Treasuries lowers the 5-year term premium by 135 basis points.

Third, following Gruber and Kamin (2012), we add 2 year ahead projections of real GDP growth rate $\mathbb{E}_t y_{i,t+2}$ which can be obtained from Consensus Economics *Consensus Forecast*, the IMF *World Economic Outlook*, *Article IV Consultations*, OECD *Economic Outlook*, European Commission (EC) *European Economic Forecast* and the EUI.

Finally, we control the expected exchange depreciation in 2 years horizon : the rate of change between the 2-year-ahead projections of expected exchange rate and the current year estimation of exchange rate each currency against the US dollar, using *Consensus Forecast*. As foreign investors may be measuring returns in exchange rate adjusted terms, currency depreciation would cause them to demand this risk premium. Ebeke and Lu (2015) control for the 2-year forward exchange rate between each currency against the US dollar.

3. Estimation results

3.1 Baseline results

Table 2 shows the baseline results. The tests for nonlinearity are significant with p-values smaller than 0.01 [16]. Thus, we employ the interaction term model and GPSTR model instead of the linear model. This result illustrates that the composition plays an important role on the non-linear behavior of the long-term interest rate.

3.1.1 Marginal impact of the expected public debt

The main parameters of interest here are β_0 and β_1. As expected, β_1 is larger than β_0 in the interaction term model, PSTR and GPSTR model. These results illustrate that the more the public debt is financed by foreign private investors, the greater the impact of the increase in the expected public debt on forward interest rate is.

[16] In the linearity test, we follow Luukkonen et al. (1988) and Terasvirta (1994), replacing the transition function $g(\cdot)$ of GPSTR with the first-order Taylor expansion (Please see Appendix A.1 for the detail). The conversion gives the interaction term model. Hence, tests of the interaction model and GPSTR for nonlinearity show the same results.

Figure 5 shows the marginal impact of the expected public debt on the interest rate ($\frac{\partial \mathbb{E}_t L_{i,t+n}}{\partial \mathbb{E}_t Debt_{i,t+n}}$). One striking feature of this chart is that this estimated impact by GPSTR increases exponentially and significantly as the foreign private holdings ratio exceeds the location parameter while the corresponding impact by the interaction term increases constantly and that by PSTR becomes flatten. The right panel of Figure 5 show if the share of foreign investors are 20, 30 and 40 percent, the marginal impacts of public debt on the interest rate are 1.6, 3.2 and 5.2 percent points, respectively. The result of GPSTR is consistent with the dynamic stochastic general equilibrium (DSGE) studies such as Schmitt-Grohe and Uribe (2003), Adolfson et al. (2007) and García-Cicco et al. (2010) which assume an exponential relationship between risk premia and foreign debt. As shown in Figure 1, as the share of foreign private investors has increased substantially in emerging markets, the interest rate could be more sensitive to the expected public debt[17].

In contrast, when foreign private holdings ratios are below 17 percent, the result of GPSTR illustrates that there is no significant impact of public debt on long-term government bond yields (5). This implies that domestic investors are insensitive to the expected public debt. In other words, domestic investors may not require a risk premium against large debt when there is a strong home bias without any other assets hedging fiscal risk, which is line with Japan's debt literature (Sakuragawa and Sakuragawa (2016)).

3.1.2 Marginal impact of the share of foreign private investors

Another parameter of interest here is the coefficients for the share of foreign private investors;δ. According to Table 2, the increase in foreign private holdings of government debt is associated with a reduction of the interest rate, which is consistent with the literature (Arslanalp and Poghosyan (2016) and Ebeke and Lu (2015)). It would put downward pressure on long-term interest rates by expanding market liquidity.

Figure 6 shows the marginal impact of the share of foreign investor on the long-term interest rates ($\frac{\partial \mathbb{E}_t L_{i,t+n}}{\partial fp_{i,t-1}}$) . The left panel of Figure 6 from the result of the interaction term model shows that this impact varies, depending on the public debt to GDP ratio. One striking feature of this chart is that when the expected public debt $\mathbb{E}_t Debt_{i,t+n}$ is estimated be about 120 percent to GDP ratio when the marginal impact of the share of foreign private investors on the interest rate is zero. That is, although the increase in foreign private holdings of government debt is associated with a reduction of the interest rates, this downward effect would be reversed if

[17] Mendoza and Ostry (2008) argue that the riskier fiscal and financial environment in emerging markets require a stronger response to maintain fiscal solvency.

the expected public debt-to-GDP ratio exceeds this threshold value. However, the left panel of Figure 7 shows the confidence band for this threshold value is not narrow when the marginal impact of the share of foreign private investors on the interest rate is zero.

The right panel of Figure 6 from GPSTR model shows that the marginal impact of the share of foreign investor on the long-term interest rates also depend on the composition of debt as well as the expected public debt. The expected public debt $\mathbb{E}_t Debt_{i,t+n}$ that triggers a surge in government bond yields through the increase in the share of foreign investors. Given that the marginal impact of the share of foreign private investors on the interest rate is zero, the threshold of expected public debt is high when the share of foreign investors is low and vice versa: the threshold of expected public debt is low when the share of foreign investors is high. For example, when the share of foreign investors is 15 percent, the threshold of expected public debt is 91 percent. In contrast, when the share of foreign investors is 30 percent, it is 59 percent. As the impact of public debt on the interest rate of GPSTR continues to increase exponentially depending on the foreign private holdings ratio, the increase in foreign private holding of government debt would cause a rise of long-term interest rates even the debt level is low. Hence, the result of GPSTR is much different from those of the interaction term and PSTR[18].

3.2 Robustness check

We consider a wide range of exercises to check the robustness of our headline findings with the following specifications: controlling the global factor and country-specific factors.

3.2.1 Global factor

Robustness check 1(Controlling US monetary condition): The baseline might already incorporate the global factors because it included the share of foreign investors. A growing literature also investigates how bond spread especially in emerging markets are related to the global factors. For example, Mauro et al. (2002) and González-Rozada and Levy Yeyati (2008) concludes that spread comoves across emerging markets, tend to be most related to global events and global liquidity, using sovereign bonds denominated in U.S. dollars (EMBI

[18]As shown in the central panels of Figure 6 and 7 for PSTR model, there are the same marginal impacts of the share of foreign investor on the long-term interest rates over the location parameter because of the assumption of the point symmetry. This result, which it is difficult to interpret is one reason why we develop the GPSTR model to investigate the point asymmetry.

is drawn from J.P. Morgan). Longstaff et al. (2011) also find similar evidence using sovereign CDS market where the reference obligation is a US dollar-denominated issue or a Euro-dominated issue. Foley-Fisher and Guimaraes (2013) also examine the impact of changes in U.S. real interest rates on sovereign default risk in emerging market using EMBI.

While the foreign currency bonds have been widely used by previous works as above, the recent literature also has argued the local currency bonds as well. For instance, Gilchrist et al. (2018) analyze the effect of US monetary policy and local currency sovereign yields.

Although the baseline might already incorporate the global factors by the share of foreign investors, we control U.S. 10-year term premia based on Adrian and Crump (2013), excluding the observation in the U.S from the sample [19].

3.2.2 Country-specific factors

Robustness check 2 (Excluding exchange rate risk): The baseline included both the share of foreign investors and the expected exchange depreciation as the independent variables. Although we took a lagged value of foreign investors, the share of foreign investors may decline by the expected exchange depreciation if they take the forward-looking behavior. As there may be multicollinearity, we exclude the expected exchange depreciation.

Robustness check 3 (Controlling the net foreign assets position): Following Brzoza-Brzezina and Kotlowski (2018), we control the lagged net foreign assets to GDP ratio $NFA_{i,t-1}$. Reinhart and Trebesch (2015) argue that an increase in the share of foreign investors is associated with lower long-term interest rates because these holdings supplement domestic saving in capital-scarce countries. In contrast, a chronic excess of saving over investment may cause real interest rates low. We check the robustness of the baseline, even controlling this variable.

[19] We directly control the US monetary condition. However, as the risk-taking behavior of investors amid low interest rates of advanced economies, "search-for-yield" could cause the share of private foreign investors to increase in Emerging markets. There may be multicollinearity. Therefore, future research could control the US monetary condition indirectly by the instrumental variables for dealing with the endogeneity of the share of foreign investors without taking a lagged value. Moore et al. (2013) show that a 1 percentage point drop in the US 10-year Treasury bond yield leads on average to a 4.2 percentage in the percentage of foreign holdings of government bonds in emerging markets. However, Yu (2013) find the inconsistency of two step least squares estimators in threshold models when the threshold variable is endogenous. Caner and Hansen (2004) use two step least square estimators in the threshold model in which they allow for endogenous regressors, but they assume the threshold variable to be exogenous. Furthermore, Yu (2013) point out that the estimator based on a misspecified reduced form is inconsistent even if the threshold variable is exogenous. Employing the instrumental variables is an interesting future topic for research.

Robustness check 4 (Controlling the capital control): The capital control would lower the sovereign risk because the regulation of capital flows may be possible to prevent crises (Wright (2006)). Fernández et al. (2016) construct the index that represents the existence of the capital control for bond inflow and outflow restrictions. Hence, we add this capital control dummy variable $CC_{i,t-1}$ to examine for the additional robustness check.

According to Table 3 and 4, the results for the robustness checks (R1,R2, R3, and R4) are line with the baseline results. There is no significant impact of public debt on long-term government bond yields when foreign private holdings ratios are below 20 percent. The results for the marginal impact of the share of foreign investors are also similar. The estimated impact of 1 percent point increase in U.S. 10-year term premia is about 0.5 percentage point. Instead, the marginal impact of the share of foreign investors becomes smaller than the baseline because US monetary condition affects the behavior of foreign investors. In addition, the corresponding impact of the public debt is also slightly smaller than the baseline. The result of (R3) and (R4) show both the higher net foreign assets position and the capital control lower the interest rates.

3.3 Model evaluation

The interaction term, PSTR, and GPSTR are competing models because non-linearity tests reject the null hypothesis of the linear model. While many studies on the time series models have proposed the evaluation techniques, those of panel data model have not been developed well except Granger and Huang (1997). As argued by Granger (2001), it is well known that nonlinear models are inclined to overfit the data and so, out-of-sample forecasting evaluation is recommended. Hence, we employ the cross-validation suggested by Granger and Huang (1997) to calculate the mean squared error (MSE) and examine the sum-difference test to investigate whether MSE of GPSTR is statistically different from those of the interaction term model and PSTR[20].

Table 5 shows the comparison of MSE and illustrates that out-of-sample forecast errors of GPSTR are smaller than that of the interaction term model for all cases. This means that the GPSTR model is robust against the sample selection. Table 6 shows the result of sum-difference tests, illustrating the performances for the out-of-sample forecast of GPSTR are statistically better than others.

[20]Please see Appendix A4 in detail.

3.4 Comparison with other studies

Table 7 compares our estimates with those obtained in other studies for three aspects: (1) the impact of the increase in expected public debt on government bond yields, (2) the impact of the increase in the share of foreign investors on government bond yield, and (3) the threshold value for the impact of the increase in the share of foreign investors.

First, significant research has been devoted to estimating the positive impact of public debt on long-term interest rates, focusing on government debt securities denominated in local currency. The corresponding impacts in advanced economies are smaller than those in emerging markets(Arslanalp and Poghosyan (2016), Gruber and Kamin (2012), Ichiue and Shimizu (2015) and Jaramillo and Weber (2013))[21]. Our result shows that the more the public debt is financed by foreign private investors, the greater the impact of the increase in the expected public debt on forward interest rate is. Overall, the range of our estimated impacts of an increase in public debt on long-term interest rates is consistent with the literature.

Second, our result shows that the increase in foreign private holdings of government debt is also associated with a reduction of long-term interest rates, which is consistent with the literature (Arslanalp and Poghosyan (2016) and Ebeke and Lu (2015)).

Third, Ebeke and Lu (2015) show that in emerging markets an increase in the share of foreign holdings has a negative impact on yield but if either the lagged external debt-to-GDP ratio exceeds 90 percent or the lagged short-term debt-to-GDP ratio exceeds 21.5 percent, the corresponding impacts turn positive by using the interaction term including these two variables. Our corresponding result from GPSTR model is that the threshold of expected public debt is high when the share of foreign investors is low and vice versa: the threshold of expected public debt is low when the share of foreign investors is high. For example, when the share of foreign investors is 15 percent, the threshold of expected public debt is 91 percent. In contrast, when the share of foreign investors is 30 percent, it is 59 percent. As the marginal impact of the expected public debt on the interest rate of GPSTR continues to increase exponentially, depending on the foreign private holdings ratio, the increase in foreign private holdings of government debt would cause a rise of long-term interest rates even the debt level is low. Hence, the result of GPSTR is much different from that of the interaction term model.

[21] As the studies employ different sample periods, they are not necessarily comparable.

4. Conclusion

In summary, this paper investigates the threshold values to understand the non-linear behavior of the long-term interest rate by developing the novel approach : the panel smooth transition regression with the general logistic model (GPSTR) . We examine how the interaction between the funding source and the expected public debt affects the interest rates in 11 advanced economies and 14 emerging markets with forecast data. Our main finding is threefold:

(i) The impact of the expected public debt on the interest rate would increase exponentially and significantly as the foreign private holdings ratio exceeds approximately 20 percent. Otherwise, strong home bias would mitigate the upward pressure of the increase in public debt on the interest rate.

(ii) If the expected public debt-to-GDP ratio exceeds the certain level that depends on the funding source, the increase in foreign private holding of government debt would cause a rise of long-term interest rates, offsetting the downward effect on long-term interest rates by expanding market liquidity.

(iii) The out-of-sample forecast of GPSTR is more accurate than those of previous other methods: the interaction term model and PSTR.

Consequently, the composition of government debt plays an important role on the highly non-linear behavior of the long-term interest rate. This is an important result for policy makers to analyze the fiscal sustainability because they have to consider how the government bond yield reacts to the public debt. Especially, as the share of foreign private investors in the small open economy is easily affected by the capital flow, the sovereign risk would be changeable for the short-term. From a long-term perspective, Hoshi and Ito (2014) point out that the increase in local currency-denominated domestic assets would slow down due to the rapid aging of the population in Japan. As the government cannot rely on the private domestic investors in some points, the foreign investors would have to step in and absorb the government debt. Consequently, the sovereign risk would be more sensitive than before.

For future research, we could deal with the endogeneity of the share of foreign investors using the instrumental variables. This study took a lagged value of foreign investors to avoid a simultaneity bias and maintained assumption of exogeneity. However, it could relax this assumption by allowing for endogenous regressors although that might be econometrically challenging[22].

[22]Please see Section 3.2 for the detail.

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Table 2: Baseline results

Model	IT	PSTR	GPSTR
LM_F nonlinearity tests	10.5	10.5	10.5
p-value	0.00***	0.00***	0.00***
Location parameter(c)		0.288	0.092
Slope parameter1(γ_1)		15.3	-64.0
Slope parameter2(γ_2)			3.0
$\mathbb{E}_t Debt_{i,t+2}$	-0.008	0.000	-0.196***
	(0.01)	(0.01)	(0.03)
$\mathbb{E}_t Debt_{i,t+2} \cdot fp_{t-1}$	0.120***		
	(0.03)		
$\mathbb{E}_t Debt_{i,t+2} \cdot g(\cdot)$		0.051***	0.402***
		(0.01)	(0.06)
$\mathbb{E}_t y_{i,t+2}$	-0.008	0.000	0.042
	(0.14)	(0.13)	(0.13)
$do_{i,t-1}$	-0.099***	-0.085***	-0.089***
	(0.01)	(0.01)	(0.01)
$fo_{i,t-1}$	-0.146***	-0.148***	-0.153***
	(0.02)	(0.02)	(0.02)
$fp_{i,t-1}$	-0.104***	-0.105***	-0.104***
	(0.02)	(0.01)	(0.01)
$\mathbb{E}_t Exchange\ rate_{i,t+2}$	0.042***	0.043***	0.041***
	(0.01)	(0.01)	(0.01)
No. of observation	625	625	625
No. of countries	25	25	25
Sample periods	06:2-18:2	06:2-18:2	06:2-18:2

Notes: IT=Interaction term model,PSTR=Panel Smooth Transition Regression and GPSTR=General Panel Smooth Transition Regression. $\mathbb{E}_t Debt_{i,t+2}$ is 2-year ahead expected public debt to GDP ratio, $g(\cdot)$ is transition function, $\mathbb{E}_t \pi_{i,t+2}$ is 2-year ahead expected inflation, $\mathbb{E}_t y_{i,t+2}$ is 2-year ahead expected growth rate, $do_{i,t-1}$ is the lagged domestic official sector holdings ratio,$fo_{i,t-1}$ the lagged foreign official sector holdings ratio, $fp_{i,t-1}$ is the lagged foreign private sector holdings ratio and $\mathbb{E}_t Exchange\ rate_{i,t+2}$ is the rate of change between the 2-year-ahead projections of expected exchange rate and the current year estimatimation of exchange rate each currency against the US dollar. The corresponding standard error are reported in parentheses.***p<0.01, *p<0.05, *p<0.1

Figure 1: 5-to-10 year forward interest rates of government debt securities denominated in local currency

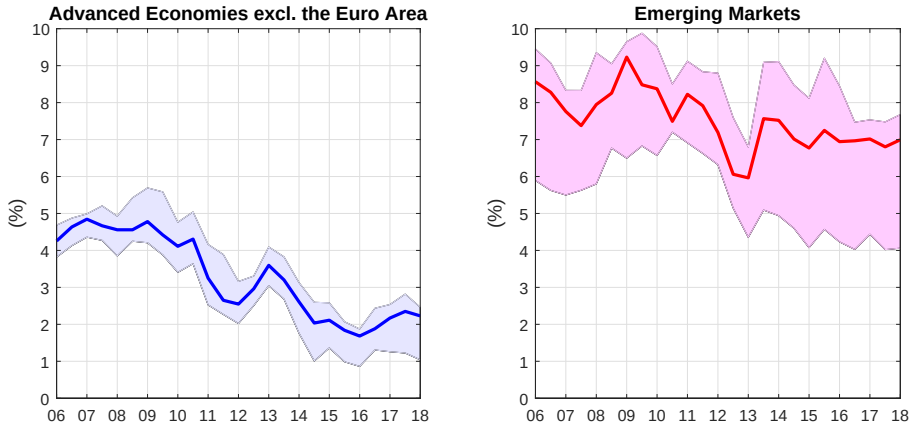


Figure 2: 2-year ahead expected public debt to GDP ratio

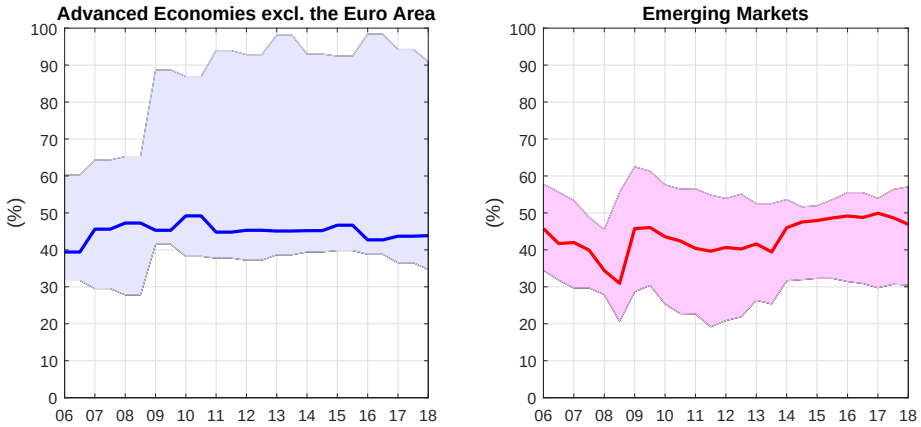
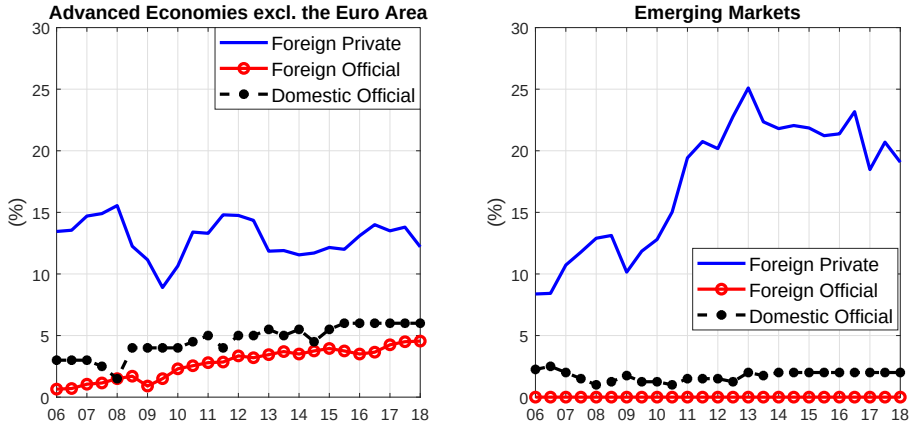
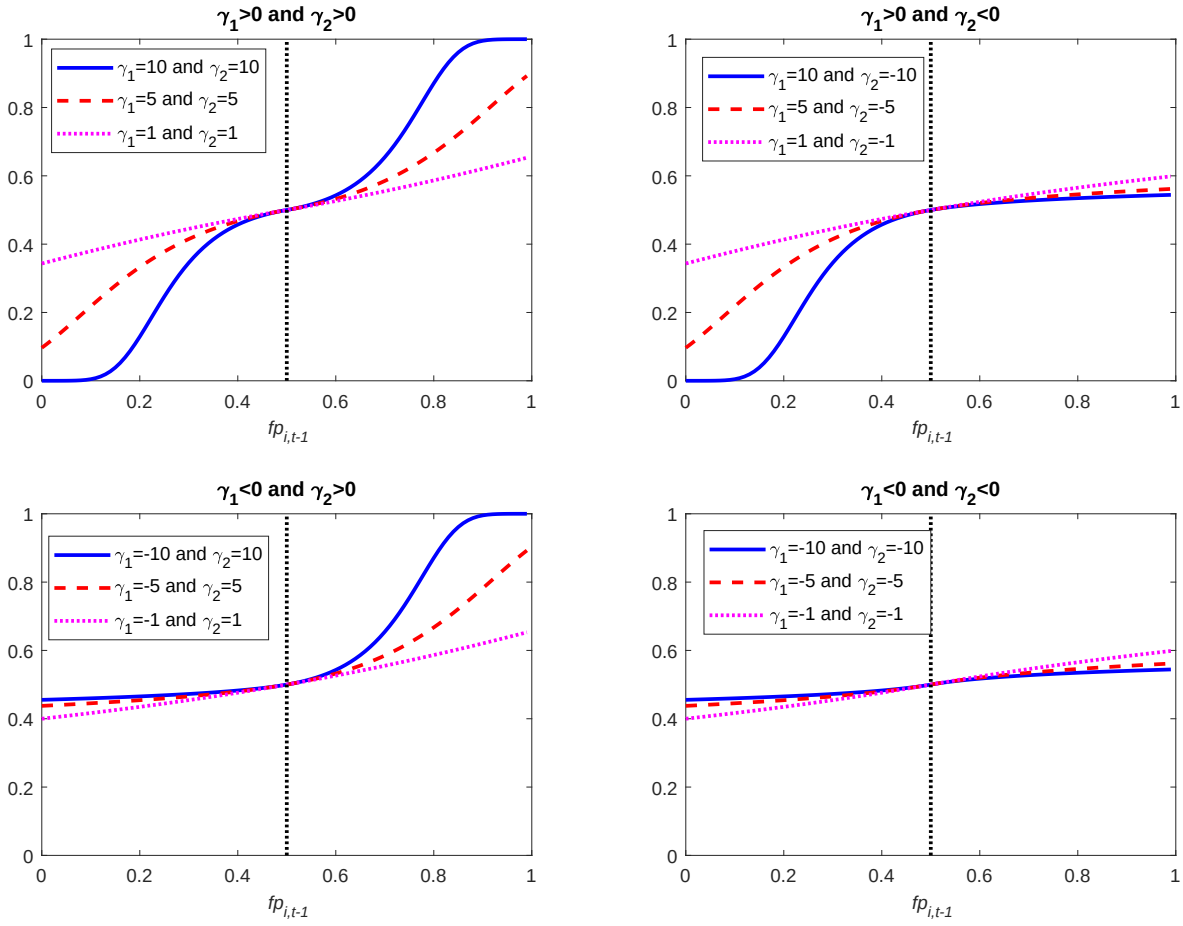


Figure 3: The share of government debt securities denominated in local currency



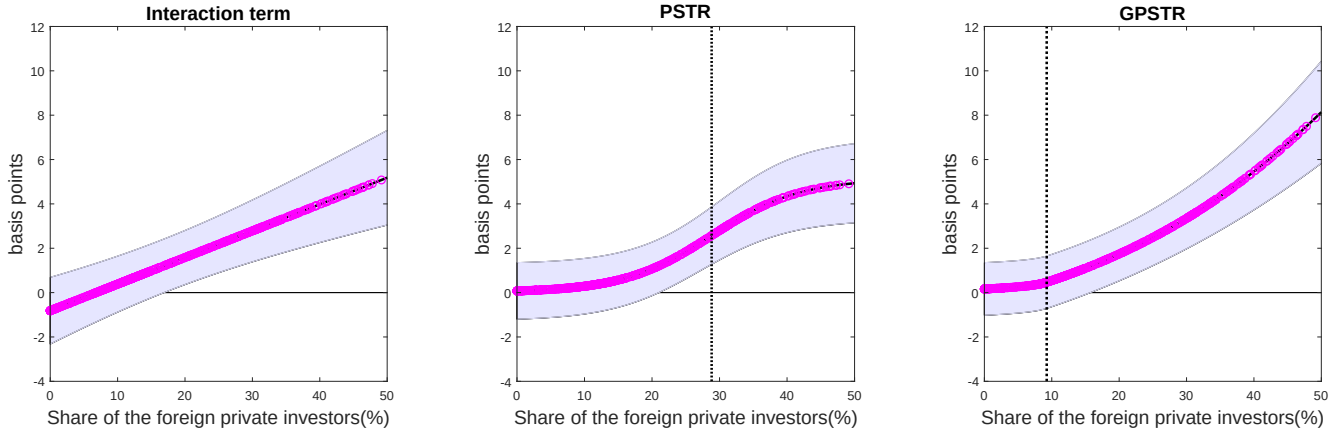
Notes: Advanced Economies excluding the Euro Area(Australia, Canada, Czech Republic, Denmark, Japan, Korea, Norway, Sweden, Switzerland , United Kingdom and United States) and Emerging Markets(Bulgaria, Columbia, China, Hungary, India, Indonesia, Malaysia, Mexico, Peru, Philippines, Poland, Thailand, Turkey and South Africa). Lines and shadow areas show the median and interquartile range within each country group, respectively. Calculations of share of governmet debt based on data from Arslanalp and Tsuda (2014a), Arslanalp and Tsuda (2014b) and BIS Debt Securities Statistics (See 2.4 Data for details).

Figure 4: Example of general logistic model (GLM) $g(fp_{i,t-1};\gamma_1,\gamma_2,c)$



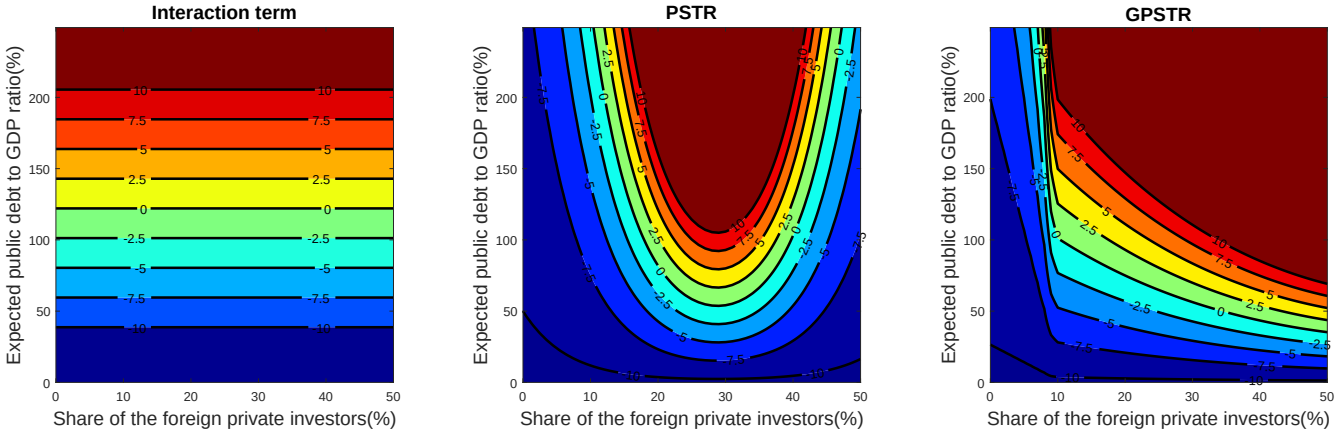
Notes: The location parameter c=*0.5*.

Figure 5: Marginal impact of the expected public debt-to-GDP ratio on the interest rate



Notes: Shadow area refers to 90 percent confidence interval. Circles correspond to observation for private foreign share.

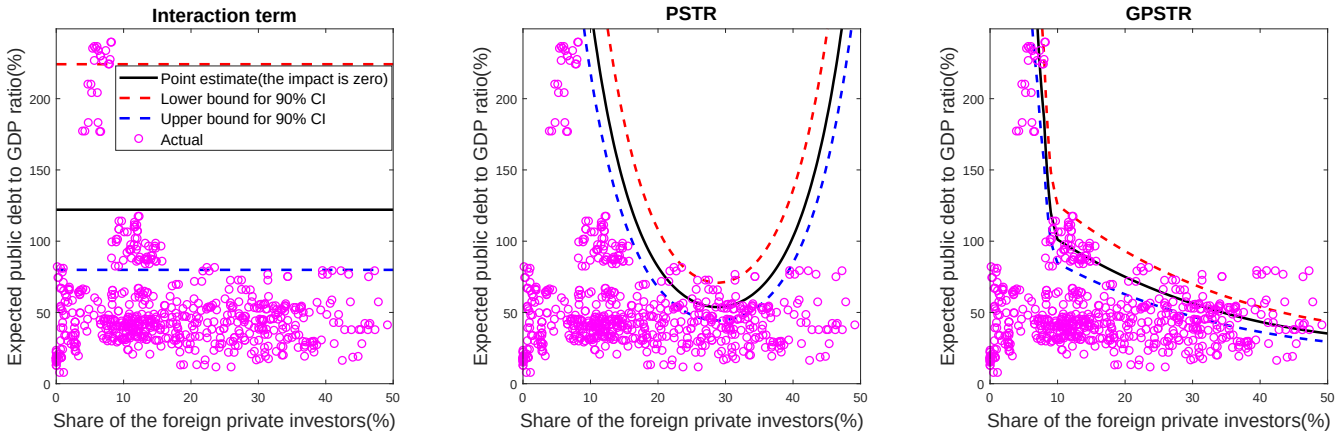
Figure 6: Marginal impact of the share of foreign private investors on the interest rate



Notes: Basis points.

Figure 7: Threshold values of the expected public debt and confidence intervals

$$\mathbb{E}_t Debt_{i,t+n} = -\frac{\delta}{\beta_1} \qquad \mathbb{E}_t Debt_{i,t+n} = -\frac{\delta}{\beta_1\left\{\frac{\partial g(fp_{i,t-1};\gamma_1,c)}{\partial fp_{i,t-1}}\right\}} \qquad \mathbb{E}_t Debt_{i,t+n} = -\frac{\delta}{\beta_1\left\{\frac{\partial g(fp_{i,t-1};\gamma_1,\gamma_2,c)}{\partial fp_{i,t-1}}\right\}}$$



Notes: Solid lines indicate combinations of the expected public debt and the share of foreign private investors given that the impact of the increase in the share of foreign private investors on forward rates is zero. Circles correspond to observation for the expected public debt and private foreign share.

Table 3: Robustness check

	(R1) IT	(R1) PSTR	(R1) GPSTR	(R2) IT	(R2) PSTR	(R2) GPSTR
LM_F nonlinearity test	9.4	9.4	9.4	11.6	11.6	11.6
p-value	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***
Location parameter(c)		0.295	0.069		0.293	0.092
Slope parameter1(γ_1)		14.3	-56.6		14.2	-51.1
Slope parameter2(γ_2)			0.03			3.1
$\mathbb{E}_t Debt_{i,t+2}$	-0.008	-0.001	-0.282	-0.007	0.001	-0.220***
	(0.01)	(0.01)	(0.05)	(0.01)	(0.01)	(0.03)
$\mathbb{E}_t Debt_{i,t+2} \cdot fp_{t-1}$	0.110***			0.127***		
	(0.03)			(0.03)		
$\mathbb{E}_t Debt_{i,t+2} \cdot g(\cdot)$		0.049***	0.557***		0.056***	0.450***
		(0.01)	(0.09)		(0.01)	(0.07)
$\mathbb{E}_t y_{i,t+2}$	-0.117	-0.111	-0.083	0.011	0.020	0.063
	(0.15)	(0.15)	(0.15)	(0.14)	(0.14)	(0.14)
$do_{i,t-1}$	-0.067***	-0.054***	-0.057***	-0.111***	-0.097***	-0.098***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
$fo_{i,t-1}$	-0.098***	-0.100***	-0.093***	-0.153***	-0.154***	-0.159***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)
$fp_{i,t-1}$	-0.080***	-0.081***	-0.082***	-0.115***	-0.115***	-0.118***
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)
$\mathbb{E}_t ER_{i,t+2}$	0.039***	0.039***	0.036***			
	(0.01)	(0.01)	(0.01)			
$US\ tp_{t-1}$	0.542***	0.543***	0.540***			
	(0.08)	(0.08)	(0.08)			
No. of observation	600	600	600	625	625	625
No. of countries	24	24	24	25	25	25
Sample periods	06:2-18:2	06:2-18:2	06:2-18:2	06:2-18:2	06:2-18:2	06:2-18:2

Notes: IT=Interaction term model,PSTR=Panel Smooth Transition Regression and GPSTR=General Panel Smooth Transition Regression. The sample of (R1) excludes the U.S. $\mathbb{E}_t Debt_{i,t+2}$ is 2-year ahead expected public debt to GDP ratio, $g(\cdot)$ is transition function, $\mathbb{E}_t \pi_{i,t+2}$ is 2-year ahead expected inflation, $\mathbb{E}_t y_{i,t+2}$ is 2-year ahead expected growth rate, $do_{i,t-1}$ is the lagged domestic official sector holdings ratio,$fo_{i,t-1}$ the lagged foreign official sector holdings ratio, $fp_{i,t-1}$ is the lagged foreign private sector holdings ratio, $\mathbb{E}_t Exchange\ rate_{i,t+2}$ is the rate of change between the 2-year-ahead projections of expected exchange rate and the current year estimatimation of exchange rate each currency against the US dollar and $US\ tp_{t-1}$ is U.S. 10-year term premia. The corresponding standard error are reported in parentheses.***p<0.01, *p<0.05, *p<0.1

Table 4: (Continued) Robustness check

	(R3) IT	(R3) PSTR	(R3) GPSTR	(R4) IT	(R4) PSTR	(R4) GPSTR
LM_F nonlinearity test	7.0	7.0	7.0	10.0	10.0	10.0
p-value	0.01***	0.01***	0.01***	0.00***	0.00***	0.00***
Location parameter(c)		0.373	0.092		0.275	0.103
Slope parameter1(γ_1)		9.6	-35.8		11.9	-74.8
Slope parameter2(γ_2)			4.0			0.3
$\mathbb{E}_t Debt_{i,t+2}$	-0.006	-0.016**	-0.162***	-0.011	-0.021***	-0.321***
	(0.01)	(0.01)	(0.03)	(0.01)	(0.01)	(0.05)
$\mathbb{E}_t Debt_{i,t+2} \cdot fp_{t-1}$	0.099***			0.119***	0.085***	0.646***
	(0.03)			(0.03)	(0.01)	(0.09)
$\mathbb{E}_t Debt_{i,t+2} \cdot g(\cdot)$		0.107***	0.331***			
		(0.02)	(0.05)			
$\mathbb{E}_t y_{i,t+2}$	-0.015	0.146	0.030	-0.041	0.121	0.037
	(0.14)	(0.10)	(0.14)	(0.12)	(0.09)	(0.12)
$do_{i,t-1}$	-0.099***	-0.038***	-0.090***	-0.094***	-0.032***	-0.089***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
$fo_{i,t-1}$	-0.142***	-0.132***	-0.149***	-0.170***	-0.154***	-0.179***
	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)
$fp_{i,t-1}$	-0.096***	-0.112***	-0.104***	-0.094***	-0.116***	-0.090***
	(0.02)	(0.02)	(0.01)	(0.02)	(0.02)	(0.01)
$\mathbb{E}_t ER_{i,t+2}$	0.029***	0.030***	0.027***	0.038***	0.044***	0.039***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
$NFA_{i,t-1}$	-0.014***	-0.017***	-0.014***			
	(0.00)	(0.00)	(0.00)			
$CC_{i,t-1}$				-3.900***	-3.006***	-4.141***
				(1.10)	(1.01)	(1.09)
No. of observation	625	625	625	625	625	625
No. of countries	25	25	25	25	25	25
Sample periods	06:2-18:2	06:2-18:2	06:2-18:2	06:2-18:2	06:2-18:2	06:2-18:2

Notes: IT=Interaction term model,PSTR=Panel Smooth Transition Regression and GPSTR=General Panel Smooth Transition Regression. $\mathbb{E}_t Debt_{i,t+2}$ is 2-year ahead expected public debt to GDP ratio, $g(\cdot)$ is transition function, $\mathbb{E}_t \pi_{i,t+2}$ is 2-year ahead expected inflation, $\mathbb{E}_t y_{i,t+2}$ is 2-year ahead expected growth rate, $do_{i,t-1}$ is the lagged domestic official sector holdings ratio,$fo_{i,t-1}$ the lagged foreign official sector holdings ratio, $fp_{i,t-1}$ is the lagged foreign private sector holdings ratio, $\mathbb{E}_t Exchange\ rate_{i,t+2}$ is the rate of change between the 2-year-ahead projections of expected exchange rate and the current year estimatimation of exchange rate each currency against the US dollar, $NFA_{i,t-1}$ is the lagged net foreign assets to GDP ratio and $CC_{i,t-1}$ is the capital control dummy. The corresponding standard error are reported in parentheses.***p<0.01, *p<0.05, *p<0.1

Table 5: Cross Validations: comparison of out-of-sample forecast errors

	(1) $\frac{MSE_{GPSTR}-MSE_{InteractionTerm}}{MSE_{InteractionTerm}} \times 100$	(2) $\frac{MSE_{GPSTR}-MSE_{PSTR}}{MSE_{PSTR}} \times 100$
Baseline	-7.3%	-4.1%
Robustness check1 (Controlling$US\ termpremium$)	-3.6%	-2.4%
Robustness check2 (excl. $Exchange\ depreciation$)	-5.6%	-2.6%
Robustness check3 (Controlling. $Net\ foreign\ assets$)	-5.2%	-10.5%
Robustness check4 (Controlling. $Capital\ control$)	-5.7%	-4.8%

Note: MSE indicates mean squared error. $MSE = \frac{1}{NT}\sum_{i=1}^{N}\sum_{t=1}^{T}\left[\widetilde{y}_{i,t} - \widehat{\Psi}_{-i}(x_{i,t}^{*})\right]^2$ where $\widehat{\Psi}_{-i}(\cdot)$ is computed by leaving out all observations of the i th cross-section.

Table 6: Sum-difference tests

	(1)$GPSTR$ vs.IT	(2) $GPSTR$ vs. $PSTR$
Baseline	-5.1***	-7.7***
	(0.00)	(0.01)
Robustness check1	-3.4***	-2.9***
(Controlling$US\ termpremium$)	(0.00)	(0.01)
Robustness check2	-4.6***	-2.9***
(excl. $Exchange\ depreciation$)	(0.00)	(0.01)
Robustness check3	-2.3**	-7.3***
(Controlling. $Net\ foreign\ assets$)	(0.03)	(0.00)
Robustness check4	-4.0***	-4.7***
(Controlling. $Capital\ control$)	(0.00)	(0.00)

Note: Sum-difference test: the null hypothesis H_0:$\theta = 0$ in the regression $SUM_{it} = \eta + \theta \cdot DIFF_{it} + \xi_{it}$ where $SUM_{it} = \hat{e}_{InterctionTerm,it} + \hat{e}_{GPSTR,it}$and $DIFF_{it} = \hat{e}_{GPSTR,it} - \hat{e}_{InterctionTerm,it}$. Estimations are based on Pooled OLS with Driscoll and Kraay (1998) standard error. Similarly, we compare GPSTR with PSTR, replacing $\hat{e}_{InterctionTerm,it}$ with $\hat{e}_{PSTR,it}$. P-values are reported in parentheses.***p<0.01, *p<0.05, *p<0.1.

Table 7: Comparison with other studies

(1) Marginal impact of expected public debt on government bond yields	basis point per 1 percent	Forecast data	Countries/Group	
This study (Baseline)	Insignificant if the share of foreign investors is below 17 percent	IMF, OECD, EC, EIU	11 AEs and 14 EMs	
	1.6(the share of foreign investors is 20 percent)			
	3.2(the share of foreign investors is 30 percent)			
	5.2(the share of foreign investors is 40 percent)			
Engen and Hubbard (2005)	2.8	CBO	U.S	
Laubach (2009)	3 to 4.4	CBO	U.S	
Traum and Yang (2015)	3	DEGE implied data	U.S	
Arslanalp and Poghosyan (2016)	2.7 to 2.8	IMF	22 AEs	
Gruber and Kamin (2012)	0.4 to 1.3	OECD	19 OECD countries	
Ichiue and Shimizu (2015)	0.7 to 0.9	OECD	10 OECD countries	
Jaramillo and Weber (2013)	4 to 6	EIU	26 EMs	
(2) Marginal mpact of the share of foreign investors on government bond yields	basis point per 1 percent	Forecast data	Countries	Investor type
This study	-11.8 to -8.2	IMF, OECD, EC, EIU	11 AEs and 14 EMs	Foreign Private
This study	-15.9 to -9.3	IMF, OECD, EC, EIU	11 AEs and 14 EMs	Foreign Official
Arslanalp and Poghosyan (2016)	-11.5 to -6.9	IMF	22 AEs	Foreign Private
Arslanalp and Poghosyan (2016)	-6.9 to -5.5	IMF	22 AEs	Foreign Official
Ebeke and Lu (2015)	-10.6 to -6.5	Actual data	13 EMs	Foreign
(3) Estimated tipping points for the impact of the increase in foreign investors	Threshold value of debt to GDP ratio	Forecast data	Countries	Investor type
This study (Baseline)	59 percent (Expected gross public debt) given that the share of foreign investors is 30 percent	IMF, OECD, EC, EIU	11 AEs and 14 EMs	Foreign Private
	91 percent (Expected gross public debt) given that the share of foreign investors is 15 percent	IMF, OECD, EC, EIU	11 AEs and 14 EMs	Foreign Private
Ebeke and Lu (2015)	90 percent (Lagged external debt)	Actual data	13 EMs	Foreign
Ebeke and Lu (2015)	21.5 percent (Lagged short-term debt)	Actual data	13 EMs	Foreign

Appendix

A.1 Linearity test

Testing the null hypothesis $H_0 : \beta_0 = \beta_1$ can examine the linearity in a GPSTR model (3). However, this test is not standard since under H_0 the GPSTR model contains unidentified nuisance parameters(Hansen (1996)). Following Luukkonen et al. (1988) and Terasvirta (1994), we replace the transition function $g(fp_{i,t-1};\gamma_1,\gamma_2,c)$ with the first-order Taylor expansion around $\gamma_1 = 0$ and $\gamma_2 = 0$. The practical computation follows two steps.

- Step1. The linearized GPSTR model is given by

$$\mathbb{E}_t L_{i,t+n} = \alpha_i + \beta_0 \mathbb{E}_t Debt_{i,t+n} + \beta_1 \mathbb{E}_t Debt_{i,t+n}.T_1(g(fp_{i,t-1};\gamma_1,\gamma_2,c)) + \delta fp_{i,t-1} + \phi \mathbf{z_{i,t}} + \varepsilon_{i,t} \tag{A.1}$$

where $T_1(g(fp_{i,t-1};\gamma_1,\gamma_2,c))$ is the first-order Taylor approximation of the transition function $g(fp_{i,t-1};\gamma_1,\gamma_2,c)$ around $\gamma_1 = 0$ and $\gamma_2 = 0$. This auxiliary regression for testing linearity can be rewritten as

$$\mathbb{E}_t L_{i,t+n} = \alpha_i + \beta_0^* \mathbb{E}_t Debt_{i,t+n} + \beta_1^* \mathbb{E}_t Debt_{i,t+n}. \cdot fp_{i,t-1} + \delta fp_{i,t-1} + \phi \mathbf{z_{i,t}} + \varepsilon_{i,t}^* \tag{A.2}$$

The sum of squared residuals is SSR_1.

- Step2. To test the null hypothesis is $H_0 : \beta_1^* = 0$, the approximate likelihood ratio of H_0 is based on

$$LM_F = TN(SSR_0 - SSR_1)/SSR_0 \tag{A.3}$$

where SSR_0 is the sum of squared residuals of the linear model $\mathbb{E}_t L_{i,t+n} = \alpha_i + \beta_0 \mathbb{E}_t Debt_{i,t+n} + \delta fp_{i,t-1} + \phi \mathbf{z_{i,t}} + \varepsilon_{i,t}$ and SSR_1 is that of the GPSTR model with two regimes.

If a p-value associated with LM_F leads us to reject the null hypothesis, we employ GPSTR model[23].

A.2 Derivatives of the transition function $g(fp_{i,t-1};\gamma_1,\gamma_2,c)$

The derivatives of the transition function $g(fp_{i,t-1};\gamma_1,\gamma_2,c)$ is needed in order to calculate the sensitivity of the long-term interest rate to the increase in the share of foreign private investors in Table 1.

[23] González and Teräsvirta (2006) use Monte Carlo testing techniques for testing linearity against smooth transition models instead of being based on an auxiliary regression obtained by replacing the model under the alternative by approximations based on a Taylor expansion.

For $fp_{i,t-1} - c \leqslant 0$

$$\frac{\partial g(fp_{i,t-1};\gamma_1,\gamma_2,c)}{\partial fp_{i,t-1}} = \begin{cases} \frac{\exp(-\gamma_1^{-1}(\log(1-\gamma_1|fp_{i,t-1}-c|)))}{(1-\gamma_1|fp_{i,t-1}-c|)\left[\exp(-\gamma_1^{-1}(\log(1-\gamma_1|fp_{i,t-1}-c|)))+1\right]^2} & \gamma_1 < 0 \\ 0 & \gamma_1 = 0 \\ \frac{\exp(\gamma_1|fp_{i,t-1}-c|)\exp(\gamma_1^{-1}(\exp(\gamma_1|fp_{i,t-1}-c|)-1))}{\left[\exp(\gamma_1^{-1}(\exp(\gamma_1|fp_{i,t-1}-c|)-1))+1\right]^2} & \gamma_1 > 0 \end{cases} \tag{A.4}$$

For $fp_{i,t-1} - c \geqslant 0$

$$\frac{\partial g(fp_{i,t-1};\gamma_1,\gamma_2,c)}{\partial fp_{i,t-1}} = \begin{cases} \frac{\exp(\gamma_2^{-1}(\log(1-\gamma_2|fp_{i,t-1}-c|)))}{(1-\gamma_2|fp_{i,t-1}-c|)\left[\exp(\gamma_2^{-1}(\log(1-\gamma_2|fp_{i,t-1}-c|)))+1\right]^2} & \gamma_2 < 0 \\ 0 & \gamma_2 = 0 \\ \frac{\exp(\gamma_2|fp_{i,t-1}-c|)\exp(-\gamma_2^{-1}(\exp(\gamma_2|fp_{i,t-1}-c|)-1))}{\left[\exp(-\gamma_2^{-1}(\exp(\gamma_2|fp_{i,t-1}-c|)-1))+1\right]^2} & \gamma_2 > 0 \end{cases} \tag{A.5}$$

A.3 Data for the composition of holdings of government bonds

While Arslanalp and Tsuda (2014b) provide foreign holdings share of central government debt securities denominated in local currency,Arslanalp and Tsuda (2014a) do not have the corresponding ratio in AEs but provides total general government debt securities including both debts denominated in foreign currency and local currency. Hence, assuming that only foreign investors hold government debt securities denominated in foreign currency (data that can be obtained from the Bank for International Settlements *Debt Securities Statistics*), we make an approximate estimate of the foreign holdings share of general government debt securities denominated in local currency by removing the amount of debt securities denominated in foreign currency from the total. Finally, we divide the foreign holdings ratio into a foreign private holdings ratio $fp_{i,t-1}$ and a foreign official holdings ratio $fo_{i,t-1}$ using data from Arslanalp and Tsuda (2014a) and Arslanalp and Tsuda (2014b).

A.4 Cross-validation and Sum-difference test

The interaction term, PSTR and GPSTR models are competing models because non-linearity tests reject the null hypothesis of the linear model. While many studies on the time series models have proposed the evaluation techniques, those of panel data model have not been developed well. Following Granger and Huang (1997) , we evaluate the interaction term model, PSTR and GPSTR model by cross-validation (CV) and examine the

sum-difference test. The practical computation follows two steps.

- Step1. By leaving out all observations of the i th cross-section, we estimates the interaction term model and GPSTR model for the new in-sample. Once we estimate parameters, we plug in all observations of the i th cross-section and then calculate the mean squared error (MSE), comparing the estimated fitted values and the actual values as below:

$$\frac{1}{NT}\hat{e}^2 = \frac{1}{NT}\sum_{i=1}^{N}\sum_{t=1}^{T}\left[\widetilde{y}_{i,t} - \widehat{\Psi}_{-i}(x_{i,t}^{*})\right]^2 \tag{A.6}$$

  where$\widehat{\Psi}_{-i}(\cdot)$ is computed by leaving out all observations of the i th cross-section. $\frac{1}{NT}\hat{e}^2_{InterctionTerm}$ and $\frac{1}{NT}\hat{e}^2_{GPSTR}$ are MSE of the interaction term model and that of GPSTR model, respectively.

- Step2. Sum-difference test: The null hypothesis H_0 is

$$H_0 : E\left[e^2_{InterctionTerm}\right] = E\left[e^2_{GPSTR}\right] \tag{A.7}$$

If H_0 is rejected, the model with the lowest MSE should be accepted as being significantly superior to the competing model. A test of the null hypothesis is equivalent to a test of whether $\theta = 0$ from the regression as follows:

$$SUM_{it} = \eta + \theta \cdot DIFF_{it} + \xi_{it} \tag{A.8}$$

where $SUM_{it} = \hat{e}_{InterctionTerm,it} + \hat{e}_{GPSTR,it}$and $DIFF_{it} = \hat{e}_{GPSTR,it} - \hat{e}_{InterctionTerm,it}$.
Similarly, we compare GPSTR with PSTR, replacing $\hat{e}_{InterctionTerm,it}$ with $\hat{e}_{PSTR,it}$.

Table A.1: Sources and description of the data

Variable Names	Description	Sources
Forward interest rate	Zero coupon rate on treasury securities in local currency	Bloomberg and Author's calculations based on Shiller et al. (1983).
Expected public debt to GDP ratio	2-year-ahead projections for general government debt to nominal GDP	IMF *World Economic Outlook*, *Article IV Consultations*, OECD *Economic Outlook* European Commission *European Economic Forecast* Economist Intelligence Unit
Expected inflation	2-year-ahead projections for headline inflation	Consensus Economics *Consensus Forecast* IMF *World Economic Outlook*, *Article IV Consultations*, OECD *Economic Outlook* European Commission *European Economic Forecast* Economist Intelligence Unit
Expected growth rate	2-year-ahead projections for real GDP growth rate	
Foreign private or official holdings ratio in Emerging Markets	Foreign holdings share of central government debt securities denominated in local currency	Author's calculations based on Arslanalp and Tsuda (2014a)
Foreign private or official holdings ratio in Advanced Economies	Foreign holdings share of general government debt securities denominated in local currency	Author's calculations based on Arslanalp and Tsuda (2014b) and BIS *Debt Securities Statistics*
Domestic central bank holdings ratio	Domestic central bank holdings share of general government debt securities	Arslanalp and Tsuda (2014a) and Arslanalp and Tsuda (2014b)
Expected exchange rate to US dollar	The rate of change between 2-year-ahead and the current estimated exchange rate	Author's calculations based on Consensus Economics *Consensus Forecast*
Treasury Term Premia	Treasury term premia based on Adrian and Crump (2013)	The website of Federal Reserve Bank of New York
Net foreign assets to GDP ratio	International Investment Position: Assets minus liabilities	IMF *International Financial Statistics* Haver Analytics
Capital control dummy	Capital control for bond inflow and outflow restrictions	Fernández et al. (2016)