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Nonlinear Exchange Rate Transmission in the Euro Area: A Multivariate Smooth Transition Regression Approach

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Abstract

This paper examines the presence of nonlinear behavior in the exchange rate pass-through (ERPT) for a set of euro area countries. We propose to solve the endogeneity problem inherent in single-equation-based methods by implementing the family of nonlinear vector smooth transition regression (VSTR) models. Using quarterly data that span from 1980:1 to 2015:4, linearity tests reveal that the ERPT responds nonlinearly to economic growth. According to the pass-through elasticities, exchange rate transmission differs significantly between the identified economic activity regimes. However, our results underscore the presence of heterogeneous profiles across the euro area economies. For some countries, the ERPT is higher during expansions than during recessions; however, the result is reversed for others. Our findings emphasize the role of a declining ERPT, as it may foster business cycle synchronization and inflation convergence within the monetary union.

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1. Introduction

Over the last two decades, there has been growing interest in examining the issue of nonlinearity in the mechanism of the exchange rate pass-through (ERPT). The behavior of some macroeconomic time series, such as exchange rate and inflation, observed over a long time, exhibits structural changes and instability, indicating the possible presence of nonlinearity and regime-switching behavior.[1] The extent to which exchange rate changes are transmitted nonlinearly to domestic prices has strong policy relevance, as monetary authorities should gauge with certainty how the ERPT is changing over time. As argued by the ERPT literature, there has been a decline in the sensitivity of domestic prices to exchange rate movements in recent years, which is clearly correlated with the shift towards a reduced-inflation regime in many countries. Several empirical studies have provided supportive evidence for strong regime dependence of the ERPT on inflation environment (see e.g. Ben Cheikh and Louhichi 2016; Shintani *et al*. 2013, among others). During periods of a stable inflation regime, domestic prices have been found to be affected less by currency changes, but inflation levels that cross a 'threshold' would lead to a higher degree of pass-through.

As a matter of fact, the causes of the decline in pass-through are difficult to pin down with certainty, and there is an ongoing debate in this regard. For example, other macroeconomic conditions, such as trade barrier tariffs, exchange rate variability, and the degree of economic integration—which have changed substantially in the last three decades—have been found to be significantly linked to the lowering ERPT (see e.g. Barhoumi 2006; Frankel *et al*. 2012; Sekine 2006).[2] Our paper suggests exploring another potential source of the observed declining pass-through, which can be a nonlinear phenomenon. As is well known, following the introduction of the single currency on January 1, 1999, there have been persistent inflation differentials across some euro area members, mainly during the first decade of the monetary union. As inflation differentials are reflective of different business cycle positions, it is interesting to examine how the economic output movements are influencing the extent of pass-through. Moreover, with the eruption of the global financial crisis in 2008/09 and the ensuing euro crisis, there have been signs of divergence in growth patterns for countries belonging to the eurozone.[3] The output volatility during the years of the Great Recession has revived concerns about persistence in inflation differentials within the context of the currency union. Thus, a better understanding of how the economic growth is influencing the ERPT mechanism is of key importance for the European monetary authorities.[4]

From an empirical point of view, models that allow for state-dependent or regime-switching behavior have been used in the existing literature to capture the potential nonlinearity in the exchange rate transmission. For instance, the class of smooth transition regression (STR) models has been successfully applied to describe the nonlinear behavior of the ERPT (see e.g. Ben Cheikh and Rault 2016; Junttila and Korhonen 2012; Nogueira and Leon-Ledesma 2008). In fact, in this line of literature, the use of single-equation STR specifications assumes that prices respond to an exogenous movement in the nominal exchange rate. However, taking the process of the exchange rate as exogenous and ignoring its potential endogeneity to other variables are to a certain extent unrealistic.[5] To solve the endogeneity problem inherent in the single-equation-based methods, recent studies have implemented multivariate threshold models, allowing them to disentangle the nonlinear ERPT dynamic (see e.g. Aleem and Lahiani 2014; Donayre and Panovska 2016). The main

[1] Koop and Potter (2000) argued that much of the evidence for nonlinearity in economic time series might in fact be due to structural change.

[2] As a matter of fact, the ERPT mechanism has both macro- and microeconomic aspects (see e.g. Campa and Goldberg 2005 for the debate about the prevalence of macroeconomic factors vs. microeconomic factors). Our study aims to provide a macroeconomic analysis of the overall effect of exchange rate changes on domestic prices, an issue that is most relevant to monetary policy issues.

[3] For a set of advanced and emerging economies, Jašová *et al*. (2015) revealed that the ERPT has changed since the recent global financial crisis, as ERPT elasticities are declining at lower rates.

[4] See Comunale and Kunovac (2017) and Özyurt (2016) for recent empirical literature on the degree of ERPT in the euro area member states.

[5] For example, according to the purchasing power parity (PPP) theory, the relative price levels may drive the exchange rate; hence, there could be two-way causality between these variables. It is therefore more appropriate to adopt an approach that treats both of them as endogenous.

drawback of their multivariate approach is that the transition across the identified economic regimes is assumed to be abrupt. While this is more plausible for describing the pricing strategies of an individual firm, at the aggregate level, a smooth transition is more realistic due to the great diversity of opinions across firms when forming their views about the macroeconomic environment in the destination country. As a remedy, our paper proposes the implementation of a nonlinear vector smooth transition regression (VSTR) model, which is a straightforward extension of the existing univariate smooth transition model to a multivariate context (see Anderson *et al*. 2007; Camacho 2004; Hubrich and Teräsvirta 2013). Within a VSTR system, we seek to remedy some of the shortcomings of the previous studies by solving both endogeneity and regime transition issues. Using quarterly data that span from 1980:1 to 2015:4 for a set of euro area countries, we begin by applying linearity tests to check whether the ERPT exhibits nonlinear behavior with respect to the state of the economy. If nonlinearity is confirmed, our multiple-equation framework allows us to derive the varying ERPT coefficients across the identified economic regimes.

The rest of this paper is organized as follows. Section 2 describes the empirical strategy and the data. In section 3, the empirical results are presented and discussed. Finally, Section 4 concludes.

2. Empirical strategy

To account for the presence of nonlinearities in the ERPT mechanism, the earlier empirical literature on the ERPT resorted to the typical single-equation STR approach. As it is also crucial to solve the endogeneity problem inherent in the single-equation-based methods, we propose to extend the typical nonlinear ERPT equation to the multivariate context. Accordingly, our paper suggests estimating a VSTR model that allows us to control for endogenous feedback effects. In line with Anderson *et al*. (2007) and Camacho (2004), a single-transition (two extreme regimes) version of the VSTR model is considered here as follows:[6]

$$\Delta y_t = \beta_{1,0} + \sum_{i=1}^{N} \beta_{i,1,1}\Delta y_{t-i} + \sum_{i=1}^{N} \beta_{i,1,2}\Delta e_{t-i} + \sum_{i=1}^{N} \beta_{i,1,3}\Delta cpi_{t-i} + \sum_{i=1}^{N} \beta_{i,1,4}\Delta w^*_{t-i}$$

$$+\left(\phi_{1,0} + \sum_{i=1}^{N} \phi_{i,1,1}\Delta y_{t-i} + \sum_{i=1}^{N} \phi_{i,1,2}\Delta e_{t-i} + \sum_{i=1}^{N} \phi_{i,1,3}\Delta cpi_{t-i}\right) G_1(s_{1,t};\gamma_1,c_1) + \varepsilon_{1,t} \quad (1)$$

$$\Delta e_t = \beta_{2,0} + \sum_{i=1}^{N} \beta_{i,2,1}\Delta y_{t-i} + \sum_{i=1}^{N} \beta_{i,2,2}\Delta e_{t-i} + \sum_{i=1}^{N} \beta_{i,2,3}\Delta cpi_{t-i} + \sum_{i=1}^{N} \beta_{i,2,4}\Delta w^*_{t-i}$$

$$+\left(\phi_{2,0} + \sum_{i=1}^{N} \phi_{i,2,1}\Delta y_{t-i} + \sum_{i=1}^{N} \phi_{i,2,2}\Delta e_{t-i} + \sum_{i=1}^{N} \phi_{i,2,3}\Delta cpi_{t-i}\right) G_2(s_{2,t};\gamma_2,c_2) + \varepsilon_{2,t} \quad (2)$$

$$\Delta cpi_t = \beta_{3,0} + \sum_{i=1}^{N} \beta_{i,3,1}\Delta y_{t-i} + \sum_{i=1}^{N} \beta_{i,3,2}\Delta e_{t-i} + \sum_{i=1}^{N} \beta_{i,3,3}\Delta cpi_{t-i} + \sum_{i=1}^{N} \beta_{i,3,4}\Delta w^*_{t-i}$$

$$+\left(\phi_{3,0} + \sum_{i=1}^{N} \phi_{i,3,1}\Delta y_{t-i} + \sum_{i=1}^{N} \phi_{i,3,2}\Delta e_{t-i} + \sum_{i=1}^{N} \phi_{i,3,3}\Delta cpi_{t-i}\right) G_3(s_{3,t};\gamma_3,c_3) + \varepsilon_{3,t} \quad (3)$$

where Δcpi_t denotes the log differences in the consumer price index (CPI), Δe_t is the change in the log of the nominal exchange rate, and Δy_t is the output growth as a proxy for the changes in the domestic demand conditions. Δw^*_t represents the changes in the foreign producer cost. Given that foreign costs are exogenously

[6] See Teräsvirta and Yang (2014) for more general representations of multitransitional VSTR models.

determined variables across our sample of eurozone countries, Δw_t^* is included in the system as an exogenous variable (see e.g. Ben Cheikh and Louhichi 2015; Choudhri *et al.* 2005).[7] $G_j(s_{j,t}; \gamma_j, c_j)$ is the transition functions driving the nonlinear behavior in the VSTR system, with $s_{j,t}$ as the transition variable, γ_j measures the speed of transition from one regime to the other, and c_j is the threshold for the transition function, with $j = 1,2,3$. For more flexibility, the transition functions are allowed to differ across our three-equation VSTR model (see Camacho 2004). Our main focus is Eq. (3), in which the long-run ERPT coefficient can be computed as follows: $\left[\sum_{i=0}^{N} \beta_{i,3,2} + \sum_{i=0}^{N} \phi_{i,3,2}\, G_3(s_{3,t}; \gamma_3, c_3)\right] / \left[1 - \sum_{i=1}^{N} \beta_{i,3,3}\right]$. The pass-through elasticity is time varying and dependent on the value of the transition function, which is bounded between zero and one. If $G_3(s_{3,t}; \gamma_3, c_3) = 0$, then the long-run ERPT is equal to $\sum_{i=0}^{N} \beta_{i,3,2} / \left(1 - \sum_{i=1}^{N} \beta_{i,3,3}\right)$; however, if $G_3(s_{3,t}; \gamma_3, c_3) = 1$, then the coefficient of the long-run ERPT is computed as $\left(\sum_{i=0}^{N} \beta_{i,3,2} + \sum_{i=0}^{N} \phi_{i,3,2}\right) / \left(1 - \sum_{i=1}^{N} \beta_{i,3,3}\right)$. Moreover, the form of the transition function will determine the nonlinear dynamic of the pass-through mechanism. Two popular choices for the transition function can be considered: on the one hand, the logistic transition function $G_3(s_{3,t}; \gamma_3, c_3) = \left[1 + exp\{-\gamma_3 (s_{3,t} - c_3)\}\right]^{-1}$, in which the ERPT coefficient varies depending on whether the transition variable $s_{3,t}$ is below or above the threshold value c_3; and, on the other hand, the exponential specification $G_3(s_{3,t}; \gamma_3, c_3) = 1 - exp\{-\gamma_3 (s_{3,t} - c_3)^2\}$, in which the rate of the ERPT changes depending on whether $s_{3,t}$ is close to or far away from the threshold c_3. The adequate form of the transition function is determined by means of a sequence of nested hypothesis tests, as in Teräsvirta (1994). As discussed above, we focus on the output growth as a driver of nonlinearity in the ERPT. Then, Eq. (3) in the VSTR system is estimated with $s_{3,t} = \Delta y_{t-i}$.

Our multivariate STR model is estimated using quarterly data over the period 1980:1 to 2015:4 for a sample of 10 euro area countries: Austria, Belgium, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, and Spain. We use the quarterly change in the CPI to provide the broadest measure of inflation at the consumer level. For the measure of changes in domestic economic activity, we use the rate of growth of the real GDP.[8] The chosen exchange rate series are the nominal effective exchange rates, in which a positive variation represents depreciation of the domestic currency. For movements in the exporters' cost, we use the proxy proposed by Bailliu and Fujii (2004), represented in logarithms by $w_t^* = q_t + ulc_t - e_t$, where q_t is the unit labor cost (ULC) based on the real effective exchange rate, ulc_t is the ULC in the domestic country, and e_t is the nominal effective exchange rate. All the data come from the International Financial Statistics (IFS) of the International Monetary Fund (IMF). For the selection of the optimal lag length entering the VSTR model, a natural method is to base the decision on the data frequency. Given the quarterly frequency of our data, it is convenient to start with a maximum lag of 4 and then remove the variables sequentially corresponding to insignificant parameter estimates (see Camacho 2004).[9]

3. Main empirical results

To derive ERPT estimates from our VSTR model, we follow the modeling strategy for multivariate STR models, as outlined by Teräsvirta and Yang (2014). The modeling strategy consists of three stages: specification, estimation, and evaluation. First, a linear VAR is specified with its maximum lag length of 4.

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[7] In their comprehensive survey of VSTR models, Hubrich and Teräsvirta (2013) explained that strongly exogeneous variables are allowed in the equations.

[8] It is possible to introduce the output gap as a proxy for shifts in economic conditions (see e.g. Correa and Minella 2006; Goldfajn and Werlang 2000; McCarthy 2007). However, it is possible that the use of the output gap would eliminate some valuable information from the real GDP data series due to ad hoc detrending processes. Following Nogueira and Leon-Ledesma (2008), we opt to estimate our VSTR models using the real output growth as a proxy for the economic activity.

[9] We check for the time series proprieties of our datasets, that is, the non-stationarity and cointegration relationship between variables in levels. Unit root tests in the spirit of Lumsdaine and Papell (1997), which allow for two structural breaks under the alternative hypothesis, confirm the non-stationarity of the variables in level. Using Gregory and Hansen's (1996) cointegration test, which explicitly incorporates a break in the cointegrating relationship, we find that the variables in level are not cointegrated. To save space, we do not list the test results here, but they are available on request. Therefore, log differences of the variables are used in the estimation of the nonlinear VSTR system.

Then, we test for linearity, and, if the null of linearity is rejected, the model selection tests are performed. Finally, the adequate model is estimated, and the adequacy tests are conducted. The way in which linearity is tested depends on the way in which the model is defined. In our case, we assume that the transition functions are not the same as in the VSTR system; then, linearity can be tested equation by equation as in the univariate case (see Teräsvirta 1994).[10] As recommended by Teräsvirta and Yang (2014), Lagrange multiplier (LM) tests are preferred, because they only require the estimation of the model under the linearity hypothesis. The linearity tests are carried out for our transition variable $s_{3,t} = \Delta y_{t-i}$, with $i = 1,2,3,4$. We begin by testing the null hypothesis H_0 of linearity. The lagged transition variable with the smallest p-value is selected as the appropriate one driving the nonlinear dynamic. If none of the p-values is sufficiently small, linearity is not rejected. If the null of the hypothesis of linearity is rejected, the appropriate functional form, that is, logistic or exponential, which drives nonlinearity, is determined through a sequential test (H_{04}, H_{03}, H_{02}).[11] The results from the linearity analysis are presented in Table I. The linearity test results show that the null hypothesis that the model is linear is rejected in eight out of ten euro area countries, the two exceptions being France and Ireland. Once the null of linearity has been rejected, test sequences are used to select the adequate form of the transition function, that is, logistic or exponential. As shown in Table I, the logistic form is found to be the best specification in most of the cases. In addition, as recommended by Camacho (2004), the final choice of the appropriate function could be determined at the evaluation stage using misspecification tests. As confirmed by Table II, the logistic VSTR model is superior to the other VSTR variant, namely exponential VSTR. We find that the logistic VSTR model has the best fit and passes most of the misspecification tests, which include the testing of the hypotheses of no error autocorrelation, parameter constancy, and no additive nonlinearity.

Table I. Linearity tests.

	$\min(H_0)$	s_t	H_{04}	H_{03}	H_{02}	Form
Austria	9.228×10^{-3}	Δy_{t-3}	1.598×10^{-2}	1.535×10^{-1}	2.789×10^{-1}	Logistic
Belgium	4.125×10^{-2}	Δy_{t-3}	2.485×10^{-2}	6.705×10^{-1}	3.924×10^{-1}	Logistic
France	1.363×10^{-1}	Δy_{t-3}	7.536×10^{-4}	7.873×10^{-1}	1.864×10^{-2}	Linear
Germany	1.245×10^{-2}	Δy_{t-3}	2.225×10^{-2}	5.511×10^{-1}	2.237×10^{-2}	Logistic
Greece	1.157×10^{-4}	Δy_{t-2}	4.758×10^{-4}	1.708×10^{-2}	2.527×10^{-1}	Logistic
Ireland	3.124×10^{-1}	Δy_{t-2}	8.864×10^{-1}	5.134×10^{-2}	1.745×10^{-1}	Linear
Italy	8.576×10^{-11}	Δy_{t-1}	5.656×10^{-2}	7.464×10^{-8}	8.498×10^{-6}	Exponential
Netherlands	5.629×10^{-3}	Δy_{t-2}	4.111×10^{-3}	2.624×10^{-1}	1.749×10^{-1}	Logistic
Portugal	2.539×10^{-2}	Δy_{t-2}	2.837×10^{-1}	5.568×10^{-2}	1.675×10^{-2}	Logistic
Spain	4.409×10^{-2}	Δy_{t-3}	5.337×10^{-1}	6.817×10^{-3}	1.679×10^{-1}	Exponential

Note: The numbers are p-values of the linearity tests. The second column shows the test of linearity against the alternative of STR nonlinearity. We select the model showing the minimum p-value, with s_t as the corresponding transition variable. From the fourth column to the sixth, we report the p-values of the sequential test (H_{04}, H_{03}, H_{02}) for choosing the adequate transition function. The decision rule is the following: if the test of H_{03} yields the strongest rejection of the null hypothesis (smallest p-value) among (H_{04}, H_{03}, H_{02}), the choice is the exponential form. Otherwise, the logistic model is selected. The last column gives the selected model.

The estimation results from Eq. (3) of our VSTR model are reported in Table II, in which results are displayed only for euro area countries rejecting the null of linearity.[12] Furthermore, Table II exhibits the

[10] If it is assumed that the transition function is the same for the whole system, a systemwise test is carry out, as discussed by Teräsvirta and Yang (2014).

[11] For details of the linearity test procedure, see Teräsvirta (1994).

[12] Our single-transition VSTR model is estimated by applying nonlinear least squares (NLS). As the transition functions are assumed to be different in the system, we proceed by estimating equation by equation as in single-equation STR models (see e.g. Hubrich and Teräsvirta 2013). In addition, misspecification tests, as proposed by Camacho (2004), which consist of an extension of Eitrheim and Teräsvirta's (1996) tests to the multivariate case, are conducted to check the adequacy of the VSTR models for the data. As shown in Table II, the estimated nonlinear models pass the diagnostic check; that is, there is no error autocorrelation, there is parameter constancy, and there is no remaining nonlinearity.

estimated long-run ERPT across the two extreme regimes, specifically low and high activity. In a low-activity regime, that is, when $G_3(\Delta y_{t-i}; \gamma_3 . c_3) = 0$, the real GDP growth is below the estimated threshold, and the long-run ERPT is computed as $\sum_{i=0}^{N} \beta_{i,3,2} / (1 - \sum_{i=1}^{N} \beta_{i,3,3})$; however, within a high-activity regime, that is, when $G_3(\Delta y_{t-i}; \gamma_3 . c_3) = 1$, the output growth surpasses the threshold value, and the coefficient for the long-run ERPT becomes equal to $(\sum_{i=0}^{N} \beta_{i,3,2} + \sum_{i=0}^{N} \phi_{i,3,2}) / (1 - \sum_{i=1}^{N} \beta_{i,3,3})$. According to the estimated slope parameter $\hat{\gamma}_3$, in most of the cases, the transition between the two identified states is rather smooth, the exception being Greece (see Fig. A1 in the Appendix).[13] As discussed by Teräsvirta (1994), the family of smooth transition models is a generalization of the threshold models, in which steep transition is nested as a special case. Moreover, contrary to the nonlinear threshold models, in which the transition across regimes is abrupt, the use of the family of STR models allows for the presence of a continuum of intermediate states between the two identified extreme regimes. With respect to the estimated thresholds, it is interesting to see that, in most of the cases, the output growth threshold values are close to zero. This would enable us to distinguish between periods of expansion and periods of recession or slowdown.

As for the pass-through coefficients, Table II reveals that the linkage between the economic activity and the ERPT is statistically significant in six of the eight eurozone countries. This means that the exchange rate transmission is found to be significantly different between low- and high-activity regimes. However, we point to the presence of heterogeneous profiles in terms of the ERPT across our sample of euro area countries. On the one hand, we find that some eurozone members have experienced a larger ERPT during periods of expansion than during periods of recession. For example, there is evidence of full pass-through for the Spanish economy during periods of expansion, that is, when the output growth is above the threshold of $\hat{c}_3 = 0.1\%$. However, the exchange rate transmission is significantly lower by about 0.20% when the Spanish output is growing under the estimated threshold, that is, when the economy is contracting. The latter results are supportive of the conventional wisdom that foreign firms tend to increase their prices during periods of prosperity, while, during an economic slowdown, firms are willing to accept adjustments to their markup to maintain their market share (see e.g. Ben Cheikh and Rault 2016; Correa and Minella 2006; Donayre and Panovska 2016; Przystupa and Wróbel 2011).[14] This positive dependence between the ERPT and the real GDP growth is confirmed by the plots in Fig. A1 in the Appendix for the cases of Austria, Germany, and Spain. On the other hand, according to Table II, the degree of ERPT depends negatively on economic activity for three eurozone countries, namely Belgium, Greece, and the Netherlands. For instance, the pass-through elasticity is equal to 0.24% during expansion episodes in Greece, while, for negative or sluggish economic growth under the threshold of $\hat{c}_3 = 2\%$, the pass-through rate increases to about 0.63%. As is well known, the degree of pass-through is tightly linked to foreign firms' perceptions of the destination country's macroeconomic environment. Then, if episodes of low/negative economic growth are perceived as a deteriorating macroeconomic environment in the importing country, foreign firms may decide to transmit exchange rate changes fully (see e.g. Nogueira and Leon-Ledesma 2011).[15]

[13] When constructing the grid search for estimating the slope parameter γ_3 and the location parameter c_3, it should be noted that the magnitude of γ_3 depends on the magnitude of the transition variable $s_{3,t}$; therefore, it is not a scale-free parameter. As recommended by Teräsvirta (1994), the transition parameter γ_3 should be standardized by dividing it by the sample standard deviation of the transition variable $\hat{\sigma}_{s_3}$.

[14] For example, using the multivariate threshold framework, Donayre and Panovska (2016) reported that the ERPT coefficients for the Mexican economy are around 4% in the low-growth regime and 7.5% in the high-growth regime after one year of shock.

[15] As stated in the empirical ERPT literature, a stable macroeconomic environment in the destination country may lead foreign firms to follow the strategy of *local-currency pricing* (LCP). Firms would absorb currency changes within their markups, which lowers the exchange rate transmission. However, with instable macroeconomic conditions, exporters would change their pricing decision by adopting the setting of *producer-currency pricing* (PCP).

Table II. Estimation results for nonlinear ERPT.

Austria

$$\Delta cpi_t = \underset{(0.217)}{0.010} + \underset{(0.147)}{0.277}\Delta y_{t-1} + \underset{(0.085)}{0.097}\Delta y_{t-2} + \underset{(0.045)}{0.040}\Delta e_{t-1} + \underset{(0.027)}{0.077}\Delta e_{t-4} + \underset{(0.140)}{0.566}\Delta cpi_{t-2} - \underset{(0.018)}{0.040}\Delta cpi_{t-4}$$

$$+\underset{(0.027)}{0.030}\Delta w^*_{t-1} + \underset{(0.107)}{0.139}\Delta w^*_{t-2} + \underset{(0.119)}{0.171}\Delta w^*_{t-4} + \left(\underset{(0.042)}{0.033}\Delta e_{t-1} - \underset{(0.083)}{0.086}\Delta e_{t-4}\right) \times G_3(\hat{s}_{3.t};\hat{\gamma}_3.\hat{c}_3) + \hat{\varepsilon}_{3.t}$$

$$\text{with} \quad G_3(\hat{s}_{3.t};\hat{\gamma}_3.\hat{c}_3) = \left[1 + \exp\left(-\underset{(0.192)}{11.003}\,(\Delta y_{t-3} - \underset{(0.000)}{0.012})\right)\right]^{-1}$$

$$pLM_{AR(4)} = 0.247; \quad pLM_C = 0.194; \quad pLM_{NRN} = 0.427$$

Long-run ERPT $[G_3(s_{3.t};\gamma_3.c_3) = 0] = \underset{(0.015)}{0.191}$ *Long-run ERPT* $[G_3(s_{3.t};\gamma_3.c_3) = 1] = \underset{(0.049)}{0.336}$

Belgium

$$\Delta cpi_t = \underset{(0.000)}{0.009} - \underset{(0.016)}{0.389}\Delta y_{t-1} + \underset{(0.000)}{0.105}\Delta e_{t-1} + \underset{(0.007)}{0.058}\Delta e_{t-2} + \underset{(0.044)}{0.024}\Delta e_{t-3} + \underset{(0.000)}{0.425}\Delta cpi_{t-4} + \underset{(0.012)}{0.168}\Delta w^*_{t-1}$$

$$-\underset{(0.090)}{0.066}\Delta w^*_{t-2} + \underset{(0.00)}{0.170}\Delta w^*_{t-3} - \left(\underset{(0.030)}{0.034}\Delta e_{t-1} + \underset{(0.075)}{0.029}\Delta e_{t-2} + \underset{(0.064)}{0.012}\Delta e_{t-3}\right) \times G_3(\hat{s}_{3.t};\hat{\gamma}_3.\hat{c}_3) + \hat{\varepsilon}_{3.t}$$

$$\text{with} \quad G_3(\hat{s}_{3.t};\hat{\gamma}_3.\hat{c}_3) = \left[1 + \exp\left(-\underset{(0.161)}{2.072}\,(\Delta y_{t-3} - \underset{(0.062)}{0.003})\right)\right]^{-1}$$

$$pLM_{AR(4)} = 0.887; \quad pLM_C = 0.268; \quad pLM_{NRN} = 0.789$$

Long-run ERPT $[G_3(s_{3.t};\gamma_3.c_3) = 0] = \underset{(0.000)}{0.327}$ *Long-run ERPT* $[G_3(s_{3.t};\gamma_3.c_3) = 1] = \underset{(0.000)}{0.197}$

Germany

$$\Delta cpi_t = \underset{(0.000)}{0.007} + \underset{(0.039)}{0.006}\Delta y_{t-1} - \underset{(0.105)}{0.041}\Delta y_{t-2} - \underset{(0.028)}{0.078}\Delta y_{t-4} + \underset{(0.069)}{0.024}\Delta e_{t-1} + \underset{(0.077)}{0.019}\Delta e_{t-4} + \underset{(0.040)}{0.352}\Delta cpi_{t-1}$$

$$-\underset{(0.073)}{0.167}\Delta cpi_{t-4} + \underset{(0.045)}{0.028}\Delta w^*_{t-1} + \underset{(0.054)}{0.039}\Delta w^*_{t-2} + \underset{(0.079)}{0.051}\Delta w^*_{t-4}$$

$$+\left(\underset{(0.052)}{0.112}\Delta e_{t-1} - \underset{(0.032)}{0.068}\Delta e_{t-4}\right) \times G_3(\hat{s}_{3.t};\hat{\gamma}_3.\hat{c}_3) + \hat{\varepsilon}_{3.t}$$

$$\text{with} \quad G_3(\hat{s}_{3.t};\hat{\gamma}_3.\hat{c}_3) = \left[1 + \exp\left(-\underset{(0.142)}{2.252}\,(\Delta y_{t-3} - \underset{(0.100)}{0.013})\right)\right]^{-1}$$

$$pLM_{AR(4)} = 0.425; \quad pLM_C = 0.576; \quad pLM_{NRN} = 0.938$$

Long-run ERPT $[G_3(s_{3.t};\gamma_3.c_3) = 0] = \underset{(0.021)}{0.088}$ *Long-run ERPT* $[G_3(s_{3.t};\gamma_3.c_3) = 1] = \underset{(0.062)}{0.183}$

Greece

$$\Delta cpi_t = \underset{(0.095)}{0.002} + \underset{(0.111)}{0.064}\Delta y_{t-1} + \underset{(0.108)}{0.067}\Delta y_{t-4} + \underset{(0.002)}{0153}\,\Delta e_{t-1} + \underset{(0.007)}{0.128}\Delta e_{t-2} + \underset{(0.000)}{0.553}\Delta cpi_{t-4} + \underset{(0.041)}{0.204}\Delta w^*_{t-1}$$

$$+\underset{(0.061)}{0.168}\Delta w^*_{t-2} - \left(\underset{(0.065)}{0.087}\Delta e_{t-1} + \underset{(0.057)}{0.089}\Delta e_{t-4}\right) \times G_3(\hat{s}_{3.t};\hat{\gamma}_3.\hat{c}_3) + \hat{\varepsilon}_{3.t}$$

$$\text{with} \quad G_3(\hat{s}_{3.t};\hat{\gamma}_3.\hat{c}_3) = \left[1 + \exp\left(-\underset{(0.146)}{20.857}\,(\Delta y_{t-2} - \underset{(0.000)}{0.020})\right)\right]^{-1}$$

$$pLM_{AR(4)} = 0.179; \quad pLM_C = 0.146; \quad pLM_{NRN} = 0.173$$

Long-run ERPT $[G_3(s_{3.t};\gamma_3.c_3) = 0] = \underset{(0.000)}{0.630}$ *Long-run ERPT* $[G_3(s_{3.t};\gamma_3.c_3) = 1] = \underset{(0.066)}{0.237}$

Italy

$$\Delta cpi_t = \underset{(0.093)}{0.001} + \underset{(0.103)}{0.041}\Delta y_{t-1} - \underset{(0.096)}{0.010}\Delta y_{t-3} + \underset{(0.045)}{0.044}\Delta e_{t-1} + \underset{(0.000)}{0.387}\Delta cpi_{t-1} + \underset{(0.000)}{0.233}\Delta cpi_{t-2} + \underset{(0.000)}{0.205}\Delta cpi_{t-4}$$

$$+\underset{(0.000)}{0.102}\Delta w^*_{t-1} + \underset{(0.119)}{0.007}\Delta w^*_{t-2} + \underset{(0.119)}{0.171}\Delta w^*_{t-4} + \left(\underset{(0.894)}{0.029}\Delta e_{t-1} - \underset{(0.083)}{0.086}\Delta e_{t-4}\right) \times G_3(\hat{s}_{3.t};\hat{\gamma}_3.\hat{c}_3) + \hat{\varepsilon}_{3.t}$$

$$\text{with} \quad G_3(\hat{s}_{3.t};\hat{\gamma}_3.\hat{c}_3) = \left[1 + \exp\left(-\underset{(0.126)}{3.395}\,(\Delta y_{t-1} - \underset{(0.000)}{0.009})\right)\right]^{-1}$$

$$pLM_{AR(4)} = 0.578; \quad pLM_C = 0.537; \quad pLM_{NRN} = 0.656$$

Long-run ERPT $[G_3(s_{3.t};\gamma_3.c_3) = 0] = \underset{(0.000)}{0.328}$ *Long-run ERPT* $[G_3(s_{3.t};\gamma_3.c_3) = 1] = \underset{(0.748)}{0.424}$

Table II. *Continued*

Netherlands

$$\Delta cpi_t = \underset{(0.259)}{-0.001} + \underset{(0.186)}{0.020}\Delta y_{t-1} + \underset{(0.122)}{0.048}\Delta y_{t-2} - \underset{(0.207)}{0.066}\Delta y_{t-4} + \underset{(0.025)}{0.043}\Delta e_{t-1} + \underset{(0.014)}{0.050}\Delta e_{t-3} + \underset{(0.490)}{0.076}\Delta cpi_{t-2}$$

$$+\underset{(0.000)}{0.478}\Delta cpi_{t-4} + \underset{(0.107)}{0.139}\Delta w^*_{t-1} + \underset{(0.119)}{0.171}\Delta w^*_{t-3} + \left(\underset{(0.148)}{0.011}\Delta e_{t-1} - \underset{(0.160)}{0.012}\Delta e_{t-3}\right) \times G_3(\hat{s}_{3.t}; \hat{\gamma}_3. \hat{c}_3) + \hat{\varepsilon}_{3.t}$$

$$\text{with} \quad G_3(\hat{s}_{3.t}; \hat{\gamma}_3. \hat{c}_3) = \left[1 + \exp\left(-\underset{(0.633)}{7.476}\,(\Delta y_{t-2} - \underset{(0.000)}{0.009}\,)\right)\right]^{-1}$$

$pLM_{AR(4)} = 0.624$; $pLM_C = 0.647$; $pLM_{NRN} = 0.638$

Long-run ERPT $[G_3(s_{3.t}; \gamma_3. c_3) = 0] = \underset{(0.000)}{0.208}$ *Long-run ERPT* $[G_3(s_{3.t}; \gamma_3. c_3) = 1] = \underset{(0.014)}{0.155}$

Portugal

$$\Delta cpi_t = \underset{(0.018)}{0.104} + \underset{(0.219)}{3.861}\Delta y_{t-3} - \underset{(0.064)}{4.165}\Delta y_{t-4} + \underset{(0.168)}{1.564}\Delta e_{t-1} + \underset{(0.198)}{0.005}\Delta e_{t-2} - \underset{(0.276)}{0.091}\Delta e_{t-4} - \underset{(0.077)}{1.631}\Delta cpi_{t-1}$$

$$-\underset{(0.257)}{1.914}\Delta cpi_{t-2} + \underset{(0.094)}{1.466}\Delta cpi_{t-4} + \underset{(0.125)}{1.941}\Delta w^*_{t-1} - \underset{(0.041)}{2.450}\Delta w^*_{t-2}$$

$$+\left(-\underset{(0.202)}{1.449}\Delta e_{t-1} + \underset{(0.259)}{0.026}\Delta e_{t-2} + \underset{(0.194)}{0.169}\Delta e_{t-4}\right) \times G_3(\hat{s}_{3.t}; \hat{\gamma}_3. \hat{c}_3) + \hat{\varepsilon}_{3.t}$$

$$\text{with} \quad G_3(\hat{s}_{3.t}; \hat{\gamma}_3. \hat{c}_3) = \left[1 + \exp\left(-\underset{(0.354)}{13.992}\,(\Delta y_{t-2} - (-\underset{(0.000)}{0.007}\,)\right)\right]^{-1}$$

$pLM_{AR(4)} = 0.158$; $pLM_C = 0.347$; $pLM_{NRN} = 0.579$

Long-run ERPT $[G_3(s_{3.t}; \gamma_3. c_3) = 0] = \underset{(0.024)}{0.479}$ *Long-run ERPT* $[G_3(s_{3.t}; \gamma_3. c_3) = 1] = \underset{(0.215)}{0.072}$

Spain

$$\Delta cpi_t = \underset{(0.460)}{0.001} + \underset{(0.001)}{0.565}\Delta y_{t-1} + \underset{(0.129)}{0.049}\Delta e_{t-1} + +\underset{(0.032)}{0.056}\Delta e_{t-2} - \underset{(0.023)}{0.077}\Delta e_{t-3} + \underset{(0.253)}{0.091}\Delta cpi_{t-2} + \underset{(0.000)}{0.765}\Delta cpi_{t-4}$$

$$+\underset{(0.002)}{0.125}\Delta w^*_{t-1} - \underset{(0.176)}{0.046}\Delta w^*_{t-2} + \left(\underset{(0.010)}{0.114}\Delta e_{t-1} - \underset{(0.066)}{0.060}\Delta e_{t-2} + \underset{(0.151)}{0.069}\Delta e_{t-3}\right) \times G_3(\hat{s}_{3.t}; \hat{\gamma}_3. \hat{c}_3) + \hat{\varepsilon}_{3.t}$$

$$\text{with} \quad G_3(\hat{s}_{3.t}; \hat{\gamma}_3. \hat{c}_3) = \left[1 + \exp\left(-\underset{(0.124)}{9.054}\,(\Delta y_{t-3} - \underset{(0.042)}{0.001}\,)\right)\right]^{-1}$$

$pLM_{AR(4)} = 0.289$; $pLM_C = 0.138$; $pLM_{NRN} = 0.458$

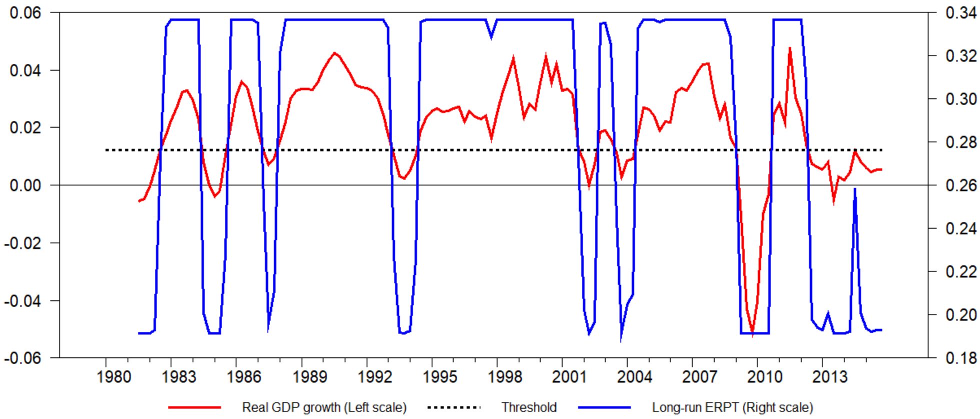
Long-run ERPT $[G_3(s_{3.t}; \gamma_3. c_3) = 0] = \underset{(0.040)}{0.198}$ *Long-run ERPT* $[G_3(s_{3.t}; \gamma_3. c_3) = 1] = \underset{(0.016)}{1.057}$

Notes: This table reports the estimation results of Eq. (3) in the VSTR system using the NLS method. Long-run ERPT is the pass-through elasticity for a low-activity regime, that is, when $G_3(s_{3,t}; \gamma_3, c_3) = 0$, and a high-activity regime, that is, when $G_3(s_{3,t}; \gamma_3, c_3) = 1$. The numbers in parentheses are the p-values of the estimates. The misspecification tests are conducted using LM-type tests: $pLM_{AR(4)}$ are the p-values of the LM test of no error autocorrelation up to the fourth order, pLM_C are the p-values of the LM test of parameter constancy, and pLM_{NRN} are the p-values of the LM test of no remaining nonlinearity.

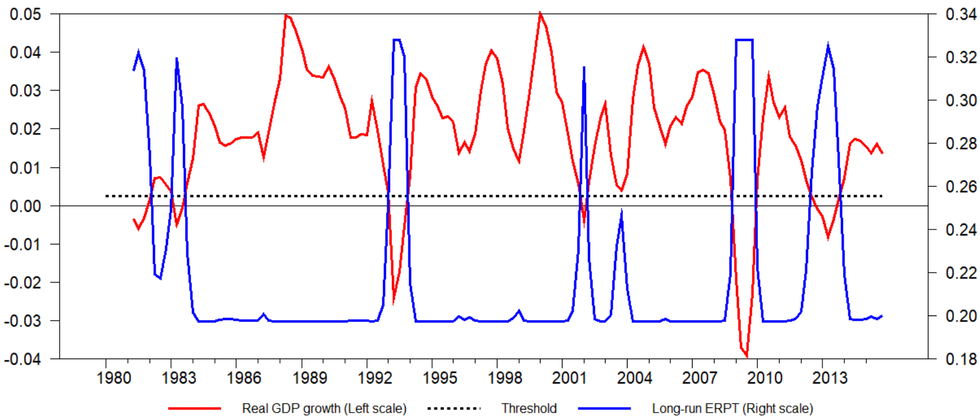
We plot in Fig. 1 the time-varying long-run ERPT coefficients over the period 1980–2015, which change depending on the developments in economic activity. It is noteworthy that there is an important difference in terms of the timing and frequency of switches between the regimes across the eurozone members. It is clear that the critical phases of the global financial crisis in 2008/09 and the ensuing European sovereign debt crisis have dramatically decreased the level of output across our sample. However, during these episodes, the exchange rate transmission has been higher mainly for the cases of Belgium and the Netherlands. The temporal pass-through dynamics is quite similar for Austria and Spain. As the growth rates have exceeded the estimated threshold levels quite frequently, the exchange transmission has tended to be higher during the whole time period. Fig. 1 corroborates our previous findings concerning the presence of important heterogeneity in the degree of pass-through across our sample of euro area countries. While our paper focuses on the ERPT from a macroeconomic perspective using aggregate price measures, it is possible that micro-level factors could also explain the cross-country differences in the pass-through rates.[16]

[16] In their sectoral study, Ben Cheikh and Rault (2017) revealed significant divergence in the product composition of imports across the eurozone members, which can account for a significant amount of the aggregate differences in the pass-through rates.

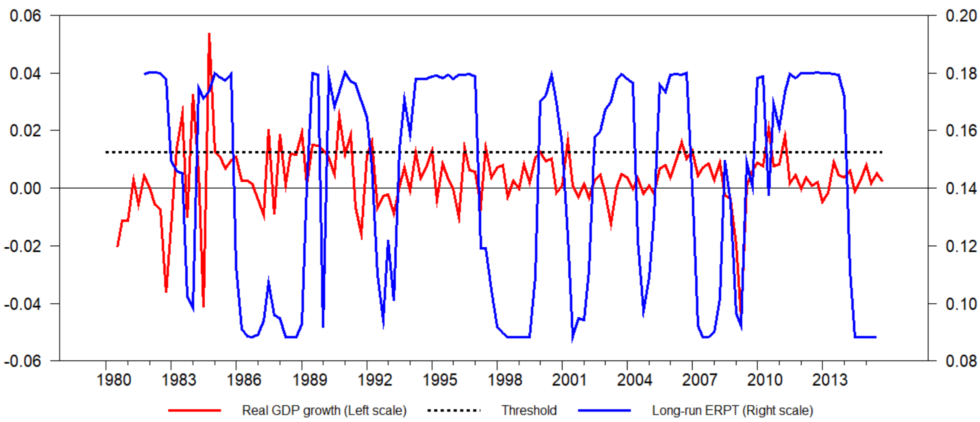
Fig. 1. Time-varying ERPT and economic growth.



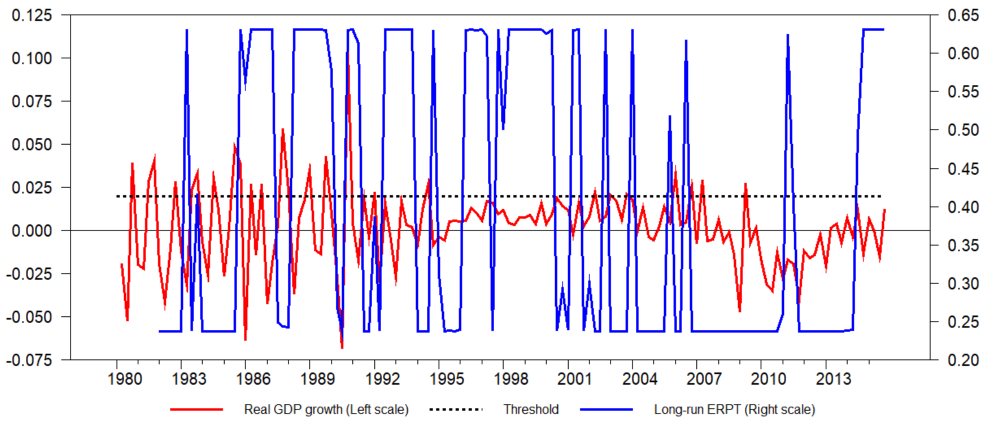
Austria



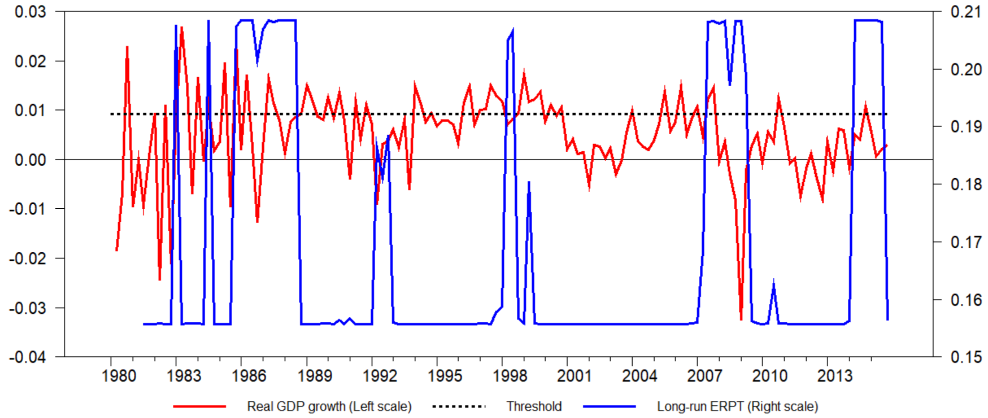
Belgium



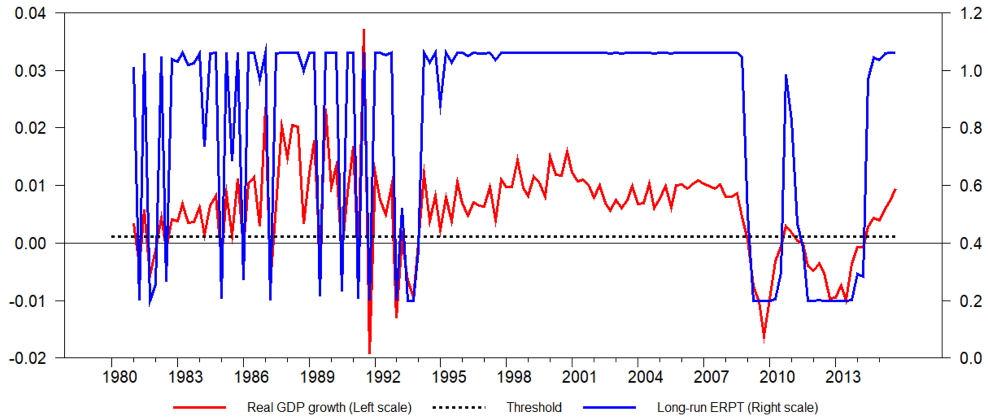
Germany



Greece



Netherlands



Spain

Notes: The time-varying ERPT (right scale), threshold level (right scale), and output growth (left scale) are plotted on the y-axis. The x-axis features the quarterly time index for the period 1980–2015. The time-varying ERPT values are obtained using Eq. (3).

The degree to which exchange rate changes are reflected in domestic prices has important implications for the appropriate stance of monetary policy in the eurozone context. As the single-currency member states still exhibit divergent growth patterns—mainly after the outbreak of the 2008–2009 financial crisis—there will be persistent heterogeneity in the ERPT mechanism, which will exacerbate the inflation differentials. As argued by Stavrev (2007), differences in business cycle positions are the main determinants of euro area inflation differentials. Then, lowering the degree of ERPT would be helpful for the European monetary authorities to reach more synchronized national cycles and ensure inflation convergence.

4. Conclusion

In this study, we investigate the possible nonlinear mechanism in the ERPT for a sample of 10 euro area countries. This exercise is conducted using the family of nonlinear VSTR models, which explicitly account for the potential endogeneity of the exchange rate to other macroeconomic variables. Using quarterly data over the period 1980:1–2015:4, linearity tests provide strong evidence of the presence of nonlinearity in 8 out of 10 eurozone countries. With respect to pass-through elasticities, the responsiveness of CPI inflation to exchange rate changes is found to differ significantly between the economic growth regimes identified. However, we point to the presence of important heterogeneity in the degree of pass-through across our sample of euro area countries. We find that some eurozone members have experienced a larger ERPT during periods of expansion than during periods of recession, but this result is reversed for other countries, such as Belgium, Greece, and the Netherlands. The cross-country differences in the nonlinear mechanism of the ERPT have important policy implications for the stance of monetary policy in the single-currency context. Our findings emphasize the role of a declining ERPT, as it may foster business cycle synchronization and inflation convergence within the monetary union.

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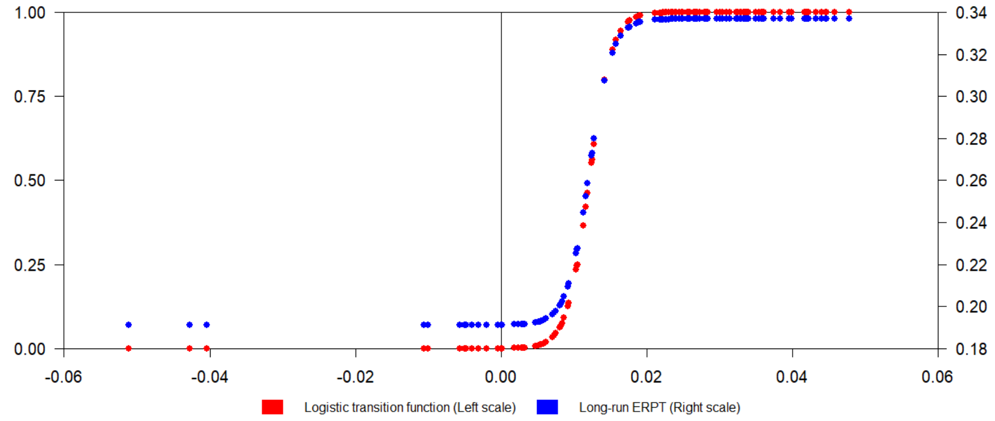
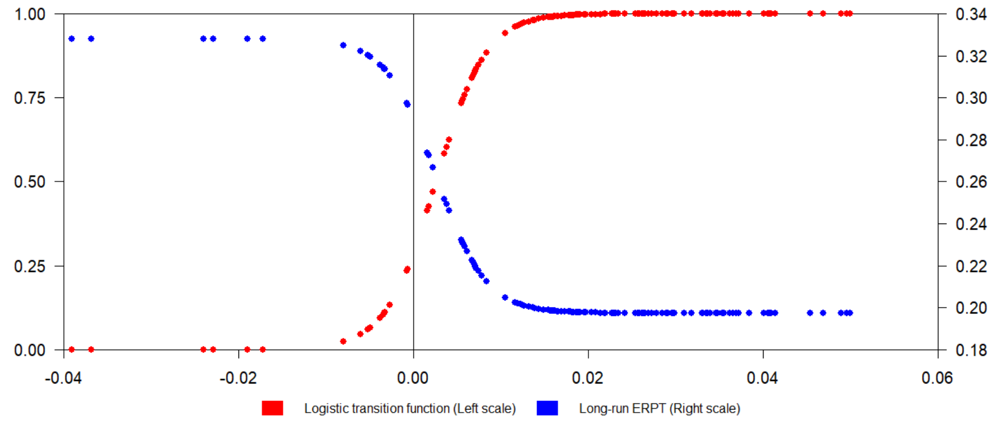
Appendix

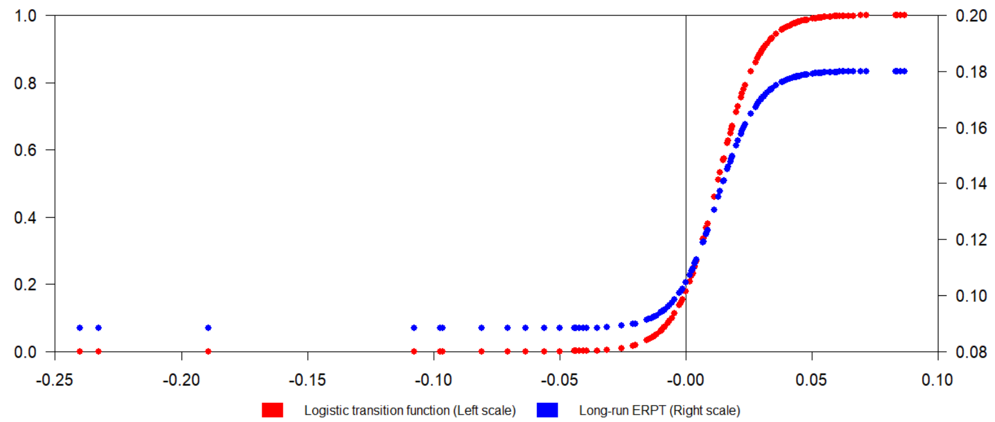
Fig. A1. Estimated transition functions and the ERPT as a function of economic growth.



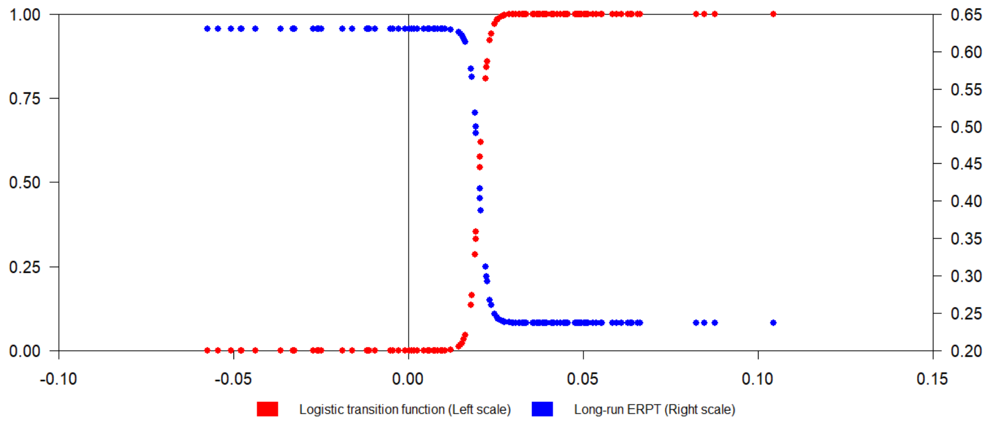
Austria



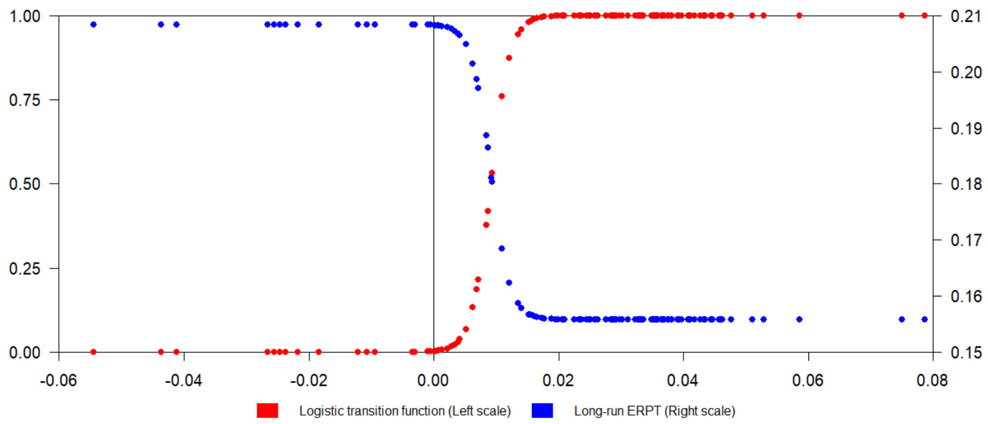
Belgium



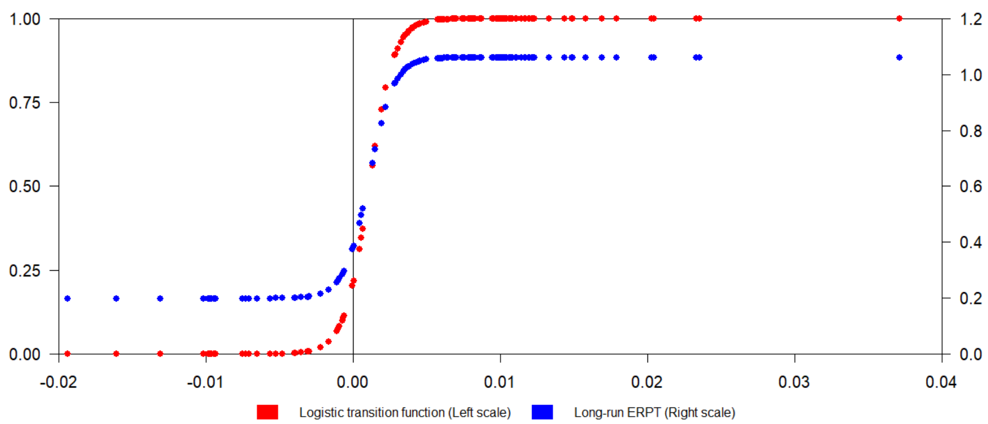
Germany



Greece



Netherlands



Spain

Notes: The estimated transition function and ERPT are plotted against the economic growth as a transition variable. x-axis: real GDP growth; y-axis: logistic transition function on the left scale and ERPT elasticity on the right scale.