Non-linearities in exchange rate pass-through: Evidence from smooth transition models

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Abstract

This paper examines the presence of non-linear mechanism in the exchange rate pass-through (ERPT) to CPI inflation for 12 euro area (EA) countries. Using smooth transition regression (STR) model, we explore the existence of non-linearities with respect to the inflation environment. We find strong evidence that pass-through respond non-linearly to inflation level for 8 out of 12 EA countries, that is, the transmission of exchange rate is higher when inflation rate surpass some threshold. Our results provide a broad support to the hypothesis suggested by Taylor (2000) that ERPT is decreasing in a lower and more stable inflation environment.

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1 Introduction

The issue of non-linearities is one of the burgeoning topics in the literature of Exchange Rate Pass-Through (ERPT)[1]. In spite of its policy relevance, studies dealing with the non-linearities in pass-through mechanisms are still relatively scarce. Mainly, the existing empirical literature on this area has put forth the role of exchange rate in generating non-linearities. In one hand, asymmetry is tested with respect to the direction of currency movements, i.e. whether ERPT respond asymmetrically to appreciations and depreciations episodes. In the other hand, what matters is the size of exchange rate changes, i.e. if ERPT would be higher for large exchange rate changes than for small ones. However, as pointed by Marazzi *et al.* (2005), previous studies provide mixed results with no clear support for the existence of important non-linearities. If the existing literature is not conclusive, there are two important caveats should be noted in this regard. First, ERPT is not depending exclusively on exchange rate changes, there are various factors, including macroeconomic variables, which might influence the pass-through mechanisms. Thus, other sources of non-linearities may exist. For instance, Goldfajn & Werlang (2000) report an asymmetric reaction of the ERPT over the business cycle. Second, a relevant econometric implement is required. Several empirical studies on asymmetries in ERPT experiment a standard linear model augmented with interactive dummy variables. These added interactive terms would account for appreciation or depreciation episodes as well as for some specific events such as unusual exchange rate developments[2]. Coughlin & Pollard (2004) use threshold dummy variables to distinguish between large and small exchange rate changes, in order to capture possible nonlinearities in ERPT. The authors choose an arbitrary threshold value for all US industries which is equal to 3%, while it is more appropriate to estimate the value from the data. An alternative methodology is to estimate a non-linear regime-switching model where a grid search is used to select the appropriate threshold. Amongst this class of models, two popular non-linear models can be mentioned. First, the so-called threshold regression model where the transition across regimes is abrupt[3]. Second, the smooth transition regression (STR) model with the transition between states is rather smooth.

In this study, we investigate for possible non-linear mechanisms in the ERPT using the family of smooth transition regression models as a tool. To the best of our knowledge, there are only two studies that using a smooth non-linear regression in the context of pass-through. Shintani *et al.* (2009) estimated the ERPT to US domestic prices with respect to inflation level. They find that the period of low ERPT would be associated with the low inflation environment. In a more complete study, Nogueira Jr. & Leon-Ledesma (2008) examine the possibility of non-linear pass-through for a set of inflation target countries. They found that asymmetric adjustment of prices to exchange rate changes can be related to several macroeconomic factors, including inflation rate, the size of exchange rate changes, macroeconomic instability and output growth[4]. Therefore, our paper aims at contributing to fill the gap in empirical evidence on the non-linearities in ERPT. We focus on "consumer-price pass-through", i.e. the sensitivity of consumer prices to exchange rate changes. We follow Shintani *et al.* (2009) by testing the presence of non-linearities with respect to the inflation environment proxied by the CPI inflation rate. The correlation between inflation regime and the degree of pass-through has put forth

[1] The exchange rate pass-through is defined as the degree to which exchange rate changes are reflected in the domestic prices. This latter may involve different prices index, especially, import prices and consumer prices.

[2] See Yang (2007).

[3] The univariate case is known as the Threshold Autoregressive (TAR) Model.

[4] Herzberg *et al.* (2003) analyzed the ERPT into UK import prices using a STR model but did not find any evidence of non-linearity.

by Taylor (2000). Known as Taylor's hypothesis, it argues that countries with low-inflation environment as a result of more credible monetary policies would experience a reduced degree of pass-through. Thus, in this paper, we raise the question of whether the inflation regime constituting a source of non-linearity in ERPT. Unlike Shintani *et al.* (2009), we are interested in the euro area (EA) case since the different macroeconomic development experienced by the monetary union members over time would generate a non-linear mechanism in ERPT. To our knowledge, there is no other study has applied a non-linear STR estimation approach in this context.

The rest of the paper is structured as follows. Section 2 discusses the analytical framework that underlies the non-linear mechanism of pass-through. In section 3, the empirical specification is presented. Section 4 gives the main empirical results and Section 6 concludes.

2 Analytical framework

Let us consider a foreign firm that exports its product i to an importing country. Under monopolistic competition, the first-order conditions for exporter profit maximization, with price set in importing country currency P_i, yield the following expression:

$$P_i = E\mu_i W_i^* \tag{1}$$

Where E is the exchange rate measured in units of the domestic currency per unit of the foreign currency, μ_i is the markup of price over marginal cost W_i^* of foreign producer. The markup is defined as $\mu_i \equiv \eta_i/(1-\eta_i)$, where η_i is the price elasticity of demand for the good i in the importing country. As in Bailliu & Fujii (2004), μ_i is assumed to depend essentially on demand pressures in the destination market: $\mu_i = \mu(Y)$, with Y is the income (expenditures) level in the importing country.

The log-linear form of equation (1) gives the standard ERPT regression traditionally tested throughout the exchange rate pass-through literature (see Goldberg & Knetter (1997))[5]:

$$p_t = \alpha + \beta e_t + \psi y_t + \delta w_t^* + \varepsilon_t, \tag{2}$$

From equation (2), the ERPT coefficient is given by coefficient β and is expected to be bounded between 0 and 1. If $\beta = 1$, exporter markup will not respond to fluctuations of the exchange rates, price is set in foreign country currency (*producer-currency pricing*, PCP) and then the pass-through is complete. If $\beta = 0$, the ERPT is zero, since foreign firm decide not to vary the prices in the destination country currency and absorb the fluctuations within the markup. This is a purely *local-currency pricing* (LCP).

In the other hand, pricing strategies of firms depend not solely on demand conditions in the market. One can think that foreign firm may adjust price after exchange rate movements with respect to some macroeconomic factors. For instance, a stable inflation environment in the destination country may lead exporters to set prices in the importer's currency by adopting LCP strategy. Firms can accommodate currency changes within markup, leading to lesser extent of pass-through. However, when the importer experience high rates of inflation, exporter would change their pricing decision by adopting PCP strategy. Accordingly, we can think that pricing

[5]For simplicity, the good superscript i is dropped and time index t is added. Lower cases variables denote logarithms.

strategy of foreign firms to depend on importer's macroeconomic environment in a non-linear framework. We consider $\kappa(M)$ as a function including those macroeconomic determinants such as inflation level. This macroeconomic dependence is seen as a firms' strategic decision on how much to translate exchange rate changes given different macroeconomic scenarios in the importing country. Taking into account these factors, we can re-write foreign firm markup as follow:

$$\mu_i = \mu(Y, E^{\kappa(M)}), \quad \kappa(M) \geq 0, \tag{3}$$

According to equation (1) and (3), ERPT equation in logarithms becomes:

$$\begin{aligned} p_t &= \alpha + \beta e_t + \psi y_t + \kappa(M) e_t + \delta w_t^* + \varepsilon_t \\ &= \alpha + [\beta + \kappa(M)]\, e_t + \psi y_t + \delta w_t^* + \varepsilon_t, \end{aligned} \tag{4}$$

According to the function $\kappa(M)$, there is an indirect channel of pass-through which depends on the macroeconomic environment. Therefore, we assume that inflation environment, as an important "macro-determinant" of ERPT, affect firm's markup in a nonlinear way. We consequently consider that there is some threshold inflation level M^* which provides two extreme macroeconomic regimes, namely high and low inflation environment regimes. The transition from one regime to the other is assumed to be smooth.

$$\kappa(M) = \begin{cases} 0 & \text{for } M \leq M^* \\ \phi & \text{for } M \geq M^* \end{cases} \tag{5}$$

According to (4) and (5), the degree of pass-through would be different and depends on whether the inflation level is above or below a threshold level. If the importing country has an inflation rate below some threshold ($M \leq M^*$), then ERPT would be equal to β. If the importing country is experiencing higher inflation level ($M > M^*$), then ERPT becomes ($\beta + \phi$). As mentioned in the literature, higher inflation environment would raise ERPT, however, with a stable inflation level pass-through would be lower. Thus, the advantage of equation (4) is to describe this changing behavior in pass-through in a non-linear fashion.

3 Empirical approach

3.1 Smooth transition regression models

To capture the non-linearity in the exchange rate transmission, we use a class of smooth transition regression (STR) models as a tool. A STR model is defined as follows:

$$y_t = \beta' \mathbf{z}_t + \phi' \mathbf{z}_t G(s_t; \gamma, c) + u_t \tag{6}$$

Where $u_t \sim \text{iid}(0, \sigma^2)$, $\mathbf{z}_t = (\mathbf{w}_t', \mathbf{x}_t')'$ is an $((m+1) \times 1)$ vector of explanatory variables with $\mathbf{w}_t' = (y_{t-1}, ..., y_{t-d})'$ and $\mathbf{x}_t' = (x_{1t}, ..., x_{kt})'$. $\beta = (\beta_0, \beta_1, ..., \beta_m)'$ and $\phi = (\phi_0, \phi_1, ..., \phi_m)'$ are the parameter vectors of the linear and the nonlinear part, respectively. $G(s_t; \gamma, c)$ is the transition function bounded between 0 and 1, and depends upon the transition variable s_t, the slope parameter γ and the location parameter c[6]. The transition variable s_t is an element of $\mathbf{z}_t$, and then is assumed to be a lagged endogenous variable ($s_t = y_{t-d}$) or an exogenous variable ($s_t = x_{kt}$).

A popular choice for the transition function is the logistic smooth transition regression (LSTR) that is given by[7]:

$$G(s_t;\gamma,c) = [1+\exp\{-\gamma(s_t - c)\}]^{-1} \tag{7}$$

Where the parameter c can be interpreted as the threshold between two extremes regimes $(G(s_t;\gamma,c) = 0$ and $G(s_t;\gamma,c) = 1)$. The non-linear coefficients would take different values depending on whether the transition variable is below or above the threshold. So, the parameters $[\beta + \phi G(s_t;\gamma,c)]$ changes monotonically as a function of s_t from ϕ to $(\beta+\phi)$. In this sense, as $(s_t - c) \to -\infty$, $G(s_t;\gamma,c) \to 0$ and coefficients correspond to β; if $(s_t - c) \to +\infty$, then $G(s_t;\gamma,c) \to 1$ and coefficients become $(\beta+\phi)$; and if $s_t = c$, $G(s_t;\gamma,c) = 1/2$ and coefficients will be $(\beta + \phi/2)$[8].

The modelling strategy of STR models is consisting of three stages: specification, estimation, and evaluation. The first stage consists in testing for non-linearity and choosing the appropriate s_t and the most suitable form of the transition function, i.e. logistic or exponential specification[9]. In the second stage, the parameters of the STR model are estimated by non-linear least squares (NLS) estimation technique which provides estimators that are consistent and asymptotically normal. As discussed in van Dijk *et al.* (2002), under the assumption that the errors are normally distributed, NLS is equivalent to maximum likelihood. Otherwise, the NLS estimates can be interpreted as quasi maximum likelihood estimates. Finding good starting values is crucial in this procedure. Thus, STR literature suggests to construct a grid search for estimating γ and c. The values for the grid search for γ were set between 0 and 100 for increments of 1, whereas c was estimated for all the ranked values of the transition variable s_t. For each value of γ and c the residual sum of squares is computed. The values that correspond to the minimum of that sum are taken as starting values into the NLS procedure. This procedure increases the precision of the estimates and ensures faster convergence of the NLS algorithm[10]. In the final stage, evaluation stage, the quality of the estimated STR model should be checked against misspecification as in the case of linear models. Several misspecification tests are used in the STR literature, such as LM test of no error autocorrelation, LM-type test of no ARCH and Jarque-Bera normality test. Eitrheim & Terasvirta (1996) suggested two additional LM-type misspecification tests: an LM test of no remaining nonlinearity and LM-type test of parameter constancy.

[6]The parameter γ is also called the speed of transition which determines the smoothness of the switching from one regime to the other.

[7]An alternative specification to the transition function is the exponential smooth transition (ESTR).

[8]It should be noted that LSTR model would follow the same pattern as the threshold model described in the theoretical model (5) but assuming a smooth adjustment between across regimes.

[9]More details for linearity tests in Appendix A.

[10]It should also be noted that when constructing the grid, γ is not a scale-free. The transition parameter γ is therefore standardized by dividing it by the sample standard deviation of the transition variable s_t.

3.2 Model specification and data

In our empirical analysis, we define a *STR pass-through* equation which is derived from the theoretical model (equation (4)). It consists of an extension of Bailliu & Fujii (2004) pass-through model to the non-linear case. Then, the equation to estimate has the following form:

$$\begin{aligned}\pi_t = \alpha + \sum_{j=1}^{N} \lambda_j \pi_{t-j} + \sum_{j=0}^{N} \psi_j \Delta y_{t-j} + \sum_{j=0}^{N} \delta_j \Delta w^*_{t-j} \\ + \sum_{j=0}^{N} \beta_j \Delta e_{t-j} + \left(\sum_{j=0}^{N} \phi_j \Delta e_{t-j} \right) G(s_t;\gamma,c) + \varepsilon_t,\end{aligned} \tag{8}$$

Where π_t is the CPI inflation rate, Δw^*_t is the changes in foreign producer cost, Δy_t is the output growth and Δe_t is the rate of depreciation of the nominal effective exchange rate. $G(s_t;\gamma,c)$ is the logistic transition function driving the non-linear dynamic. We consider the lagged inflation rate as transition variable $s_t = \pi_{t-j}$. In our analysis, we focus on the long-run pass-through (LR ERPT) which is given by the following long-run time-varying coefficients:

$$\text{LR ERPT} = \left(\sum_{j=0}^{N} \beta_j + \sum_{j=0}^{N} \phi_j G(s_t;\gamma,c) \right) / \left(1 - \sum_{j=1}^{N} \lambda_j \right) \tag{9}$$

Long-run ERPT coefficient would take different values depending on whether the transition variable is below or above the threshold. If $(s_t - c) \to -\infty$, pass-through elasticities are equal to: LR ERPT$= \sum_{j=0}^{N} \beta_j / (1 - \sum_{j=1}^{N} \lambda_j)$. If $(s_t - c) \to +\infty$, pass-through coefficients become: LR ERPT$= (\sum_{j=0}^{N} \beta_j + \sum_{j=0}^{N} \phi_j)/(1 - \sum_{j=1}^{N} \lambda_j)$.

The STR pass-through equation (8) is estimated for 12 EA countries (Austria, Belgium, Germany, Spain, Finland, France, Greece, Ireland, Italy, Luxembourg, Netherlands and Portugal), using quarterly data spanning the period 1975:1 to 2010:4. All the data we use are taken from the OECD's *Economic Outlook* database, except for exchange rate series which are obtained from *International Financial Statistics* (IFS) of the International Monetary Fund (IMF). Inflation rates series represents the quarterly change in consumer prices index (CPI). Output growth is constructed using the rate of growth of the real GDP. The nominal exchange rate is defined as domestic currency units per unit of foreign currencies, which implies that an increase represents a depreciation for home country. Finally, to capture changes in foreign costs, we follow Bailliu & Fujii (2004) by constructing an exporter partners' cost proxy. In logarithms, this latter is measured as follow: $w^*_t \equiv q_t + ulc_t - e_t$, where q_t is the unit labor cost (ULC) based real effective exchange rate, ulc_t is the ULC in domestic country and e_t the nominal effective exchange rate[11]. To determine the lag length of the variables, we follow van Dijk *et al.* (2002) by adopting a general-to-specific approach to select the final specification. We start with a model with maximum lag length of $N = 4$, and then dropping sequentially the lagged variables for which the t-statistic of the corresponding parameter is less than 1.0 in absolute value.

[11] We have checked the possibility of cointegrating relationship among our variables in ERPT equation (4). Individual series in level are non-stationary but do not appear to be cointegrated according to Engle-Granger tests. As a result, log differences of the variables are used in the estimation the STR pass-through equation as shown in equation (8). Augmented Dickey Fuller (ADF) tests suggest that variables in differences are appropriately described as stationary series.

4 Main Empirical Results

In this section we investigate whether the ERPT responds non-linearly to the inflation level in 12 EA countries. Taylor (2000) has put forward the hypothesis that the responsiveness of prices to exchange rate fluctuations depends positively on inflation. A high inflation environment tend to increase the extent of pass-through. Consequently, we aim to explore the possible regime-dependence of ERPT to inflation environment in a non-linear fashion. We consider the lagged inflation rate as the driving factor of the non-linearity, that is, $s_t = \pi_{t-j}$. The linearity tests are conducted for each lagged inflation rate π_{t-j} with $j = 1,2,3,4$. The choice of the adequate lagged inflation rate as a transition variable by means of linearity tests is reported in Table 2 in Appendix A. Accordingly, LSTR model is found to be the best specification to capture this kind of behavior for most of EA countries[12]. This is consistent with theoretical priors that pass-through mechanisms may be different whether inflation rate is above or below a given threshold. The NLS estimates of our LSTR models are summarized in Table 1. We report long-run pass-through coefficient for the two extremes regimes ($G(s_t;\gamma,c) = 0$ and $G(s_t;\gamma,c) = 1$) as defined in equation (9)[13]. We compute sum of squared residuals ratio (SSR_{ratio}) between LSTR model and the linear specification which suggests a better fit for the non-linear model. We also check the quality of the estimated LSTR models by conducting several misspecification tests. In most of cases, the selected LSTR models pass the main diagnostic tests, i.e. no error autocorrelation, no conditional heteroscedasticity, parameters constancy and non remaining nonlinearity.

ERPT results in Table 1 show significant threshold inflation rate levels for most of the EA countries. Thresholds do not differ considerably across countries. Values are ranging from 1% to 3% with exception of Portugal showing $c = 8\%$. Regarding speed of transition γ, our results indicate relatively moderate values which is a proof of smooth transition between the two inflation regimes[14]. Concerning the long-run ERPT, our results suggest a significant regime-dependence of the pass-through mechanism. There are 8 out of 12 EA countries showing a positive link between pass-through and inflation environment. That is, when inflation increases above the threshold, exchange rate transmission becomes higher. For instance, long-run ERPT in Italy is equal to 0.18% when CPI inflation is below 3%, but beyond this threshold level, ERPT becomes roughly complete by reaching 0.90%. Broadly speaking, our results are in line with Taylor's hypothesis, i.e. the responsiveness of prices to exchange rate fluctuations depends positively on inflation environment. The intuition behind this phenomenon may be due to the foreign firms' behavior. The latter are more willing to set their prices in the currency of importing countries where inflation environment is stable (LCP strategy). In such case ERPT would be lower. However, when exporters perceive a higher inflation level, they may shift away from local-currency pricing by passing exchange rate changes through the prices in importer's currency. This behavior would entail a higher degree of pass-through. From empirical point of view, our findings corroborate the scarce ERPT literature using STR models. As mentioned above, Nogueira Jr. & Leon-Ledesma (2008) has employed LSTR model to capture non-linearities in pass-through with respect to inflation rate. They conclude that the adoption of inflation target has entailed a lower pass-through for 4 countries in their sample, namely Canada, Mexico, South Africa, and United Kingdom. Similarly, Shintani *et al.* (2009) found that the period of low ERPT is likely to be associated with the low inflation environment in United States.

[12] We give preference for LSTR models with the highest R^2 and the lowest AIC criteria.

[13] Full results from all STR models are presented in the Table (3) in Appendix B.

[14] According to van Dijk *et al.* (2002) estimates of γ may appear to be insignificant. This should not be interpreted as evidence of weak nonlinearity.

Table 1: Estimated ERPT elasticities from the LSTR model with $s_t = \pi_{t-i}$

	Austria	**Belgium**	**Germany**	**Spain**	**Finland**	**France**	**Greece**	**Ireland**	**Italy**	**Luxembourg**	**Netherlands**	**Portugal**
Transition variable (s_t)	π_{t-4}	π_{t-1}	π_{t-3}	π_{t-4}	π_{t-3}	π_{t-2}	π_{t-3}	π_{t-4}	π_{t-2}	π_{t-4}	π_{t-3}	π_{t-1}
Threshold (c)	0,033	0,030	0,013	0,022	0,027	0,011	0,022	0,034	0,031	0,015	0,008	0,088
	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)	(0,024)	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)
Speed of transition (γ)	22,013	17,566	9,390	12,702	13,291	6,134	2,358	8,456	2,449	4,909	9,361	4,061
	(0,547)	(0,312)	(0,208)	(0,437)	(0,531)	(0,067)	(0,120)	(0,003)	(0,002)	(0,056)	(0,333)	(0,053)
Linear part : $G = 0$												
LR ERPT	0,154	0,140	0,115	0,438	0,415	0,086	0,168	0,440	0,183	0,436	0,131	0,059
	(0,112)	(0,000)	(0,019)	(0,246)	(0,002)	(0,108)	(0,478)	(0,036)	(0,049)	0,112)	(0,030)	(0,605)
Non-linear part: $G = 1$												
LR ERPT	0,328	0,155	0,251	0,608	0,781	0,183	0,568	2,377	0,904	1,049	0,179	0,492
	(0,027)	(0,000)	(0,192)	(0,205)	(0,249)	(0,034)	(0,103)	(0,046)	(0,036)	(0,138)	(0,018)	(0,076)
R^2	0,737	0,757	0,721	0,830	0,818	0,915	0,873	0,803	0,934	0,751	0,727	0,825
SSR_{ratio}	0,002	0,001	0,001	0,005	0,002	0,001	0,010	0,006	0,002	0,004	0,001	0,012
AIC	-8,087	-8,176	-8,338	-6,889	-7,755	-8,536	-6,337	-6,815	-7,940	-8,059	-8,184	-6,052
pJB	0,177	0,146	0,171	0,000	0,003	0,069	0,000	0,000	0,000	0,000	0,967	0,000
$pLM_{AR(4)}$	0,963	0,907	0,083	0,153	0,002	0,136	0,031	0,506	0,616	0,146	0,515	0,248
$pLM_{ARCH(4)}$	0,526	0,204	0,741	0,002	0,747	0,951	0,186	0,439	0,113	0,537	0,586	0,000
pLM_C	0,019	0,028	0,933	0,036	0,164	0,748	0,165	0,000	0,000	0,041	0,183	0,014
pLM_{RNL}	0,361	0,085	0,481	0,027	0,337	0,220	0,590	0,000	0,622	0,578	0,317	0,004

Note: Table reports elasticities of exchange rate pass-through into CPI inflation from LSTR models. Numbers in parentheses are p-values of estimates. R^2 denotes the coefficient of determination, SSR_{ratio} is the ratio of sum of squared residuals between LSTR model and the linear specification, and AIC is the Akaike Information Criterion. The following rows corresponds to the misspecification tests: pJB is the p-values of Jarque-Bera normality test, $pLM_{AR(4)}$ is the p-values of the LM test of no error autocorrelation up to forth order, $pLM_{ARCH(4)}$ is the p-values of the LM test of no ARCH effects up to forth order, pLM_C is the p-values of the LM test of parameter constancy and pLM_{RNL} is the p-values of the LM test of no remaining nonlinearity.

Additionally, we have plotted both the estimated transition functions and the ERPT as a function of the transition variable lagged inflation ($s_t = \pi_{t-i}$). Graphs of long-run pass-through are presented in Figure 1 in Appendix C[15]. It is clear that the transition between both extreme regimes, i.e. $G = 0$ and $G = 1$, is smooth in most of cases. Plots reveal the regime dependence of ERPT to inflation environment. The positive connection between the degree of the ERPT and inflation is quite clear for all of 8 EA countries. To give further insight of regime-dependence of ERPT to inflation environment, we plot the time-varying ERPT coefficients over the period 1975-2010 (see Figure 2 in Appendix C). We also report lagged inflation rates and the estimated threshold level of inflation on the same graph. A careful inspection of the plots show that the exchange rate transmission was higher during the second half of the 1970s and the early of 1980s for most of EA countries. Over this period, there had been an unstable inflation environment due especially to the oil shocks of the 1970s. During this episode, we see that inflation rates were exceeding a certain threshold level which has resulted in considerable degree of pass-through. It is worth noting that since the late 1980s and the beginning of 1990s, most of EA countries has entered an era of low inflation regime. According to Figure 2, this shifting towards stable inflation has coincided with the decline of the extent of pass-through. The bulk of recent literature of pass-through, including Bailliu & Fujii (2004), Gagnon & Ihrig (2004), has documented this lowering of the domestic price sensibility to exchange rate variation in the last two decades.

5 Conclusion

In this study, we investigate for possible non-linear mechanisms in the exchange rate pass-through (ERPT) to consumer prices for 12 euro area (EA) countries. This exercise is conducted using the family of smooth transition regression models as tool. Mainly, we explore the existence of non-linearities with respect to an important macroeconomic determinants of ERPT, namely inflation environment. Using quarterly data spanning from 1975 to 2010, we find strong evidence that pass-through respond non-linearly to inflation level. The transmission of exchange rate is higher when inflation rate surpass some threshold. We find that 8 out of 12 EA countries reveal a positive relationship between ERPT and inflation levels. Thus, we give a supportive evidence to the Taylor's view that pass-through is decreasing in a lower and more stable inflation environment. Furthermore, plots of time-varying pass-through coefficients suggest that prices sensibility to exchange rate changes has declined over time in response to a shift to a low-inflation regime.

[15] We only report results for countries with significant coefficient of pass-through.

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Appendix A. Linearity test

In order to derive a linearity test, Teräsvirta (1994, 1998) suggest to approximate the logistic function in (6) by a third-order Taylor expansion around the null hypothesis $\gamma = 0$. The resulting test has power against both the LSTR and ESTR models. Assuming that the transition variable s_t is an element in $\mathbf{z}_t$ and let $\mathbf{z}_t = (1, \tilde{\mathbf{z}}_t^{'})^{'}$, where $\tilde{\mathbf{z}}_t^{'}$ is an $(m \times 1)$. Taylor approximation yields the following auxiliary regression:

$$y_t = \alpha_0^{'} \mathbf{z}_t + \sum_{j=1}^{3} \alpha_j^{'} \widetilde{\mathbf{z}}_t s_t^j + u_t^*, \quad t = 1, ..., T, \tag{10}$$

Where $u_t^* = u_t + R_3(\gamma, c, s_t)\theta^{'}\mathbf{z}_t$, with $R_3(\gamma, c, s_t)$ the residual of Taylor expansion. The null hypothesis of linearity is $H_0 : \alpha_1 = \alpha_2 = \alpha_3 = 0$. Luukkonen *et al.* (1988) suggest a Lagrange Multiplier (LM) statistic with a standard asymptotic $\chi^2(3m)$ distribution under the null hypothesis. In small and moderate samples, the χ^2-statistic may be heavily oversized. The F version of the test is recommended instead, which has an approximate F-distribution with $3m$ and $T - 4m - 1$ degrees of freedom under H_0 (van Dijk *et al.* (2002)). Linearity tests are executed for each of the candidates potential transition variables, which are lagged inflation rates in our case.

Once linearity has been rejected, one has to choose whether logistic or exponential function should be specified. The choice between these two types of models is based on the auxiliary regression (equation (10)). Teräsvirta (1994, 1998) suggested that this choice can be based on testing the following sequence of nested null hypotheses:

1. Test $H_{04} : \alpha_3 = 0$
2. Test $H_{03} : \alpha_2 = 0 | \alpha_3 = 0$
3. Test $H_{02} : \alpha_1 = 0 | \alpha_2 = \alpha_3 = 0$

According to Teräsvirta (1994), the decision rule is the following: if the test of H_{03} yields the strongest rejection measured in the p-value, choose the ESTR model. Otherwise, select the LSTR model. All three hypotheses can simultaneously be rejected at a conventional significance level, that is why the strongest rejection counts. This procedure was simulated in Teräsvirta (1994) and appeared to work satisfactorily.

Table 2: Linearity tests against STR model with $s_t = \pi_{t-j}$

	Austria				Belgium				Germany			
	π_{t-1}	π_{t-2}	π_{t-3}	π_{t-4}	π_{t-1}	π_{t-2}	π_{t-3}	π_{t-4}	π_{t-1}	π_{t-2}	π_{t-3}	π_{t-4}
H_0	0,455	0,930	0,552	0,013	0,017	0,054	0,000	0,174	0,359	0,549	0,003	0,691
H_{04}	0,588	0,883	0,427	0,019	0,461	0,592	0,123	0,038	0,295	0,394	0,007	0,981
H_{03}	0,285	0,567	0,860	0,262	0,038	0,096	0,514	0,910	0,739	0,866	0,032	0,033
H_{02}	0,238	0,880	0,329	0,229	0,020	0,025	0,000	0,252	0,294	0,433	0,601	0,078
Model	Linear	Linear	Linear	LSTR	LSTR	Linear	LSTR	Linear	Linear	Linear	LSTR	Linear
	Spain				**Finland**				**France**			
	π_{t-1}	π_{t-2}	π_{t-3}	π_{t-4}	π_{t-1}	π_{t-2}	π_{t-3}	π_{t-4}	π_{t-1}	π_{t-2}	π_{t-3}	π_{t-4}
H_0	0,000	0,000	0,000	0,004	0,000	0,000	0,000	0,019	0,000	0,000	0,001	0,000
H_{04}	0,040	0,556	0,001	0,042	0,087	0,028	0,047	0,006	0,000	0,005	0,052	0,243
H_{03}	0,000	0,576	0,011	0,478	0,150	0,002	0,001	0,146	0,020	0,512	0,200	0,004
H_{02}	0,000	0,000	0,010	0,002	0,000	0,000	0,002	0,717	0,012	0,001	0,001	0,001
Model	ESTR	LSTR	LSTR	LSTR	LSTR	LSTR	ESTR	LSTR	LSTR	LSTR	LSTR	LSTR
	Greece				**Ireland**				**Italy**			
	π_{t-1}	π_{t-2}	π_{t-3}	π_{t-4}	π_{t-1}	π_{t-2}	π_{t-3}	π_{t-4}	π_{t-1}	π_{t-2}	π_{t-3}	π_{t-4}
H_0	0,001	0,072	0,020	0,058	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,001
H_{04}	0,090	0,820	0,016	0,011	0,000	0,002	0,000	0,000	0,001	0,032	0,149	0,061
H_{03}	0,241	0,669	0,642	0,730	0,000	0,000	0,000	0,016	0,000	0,004	0,000	0,060
H_{02}	0,000	0,000	0,057	0,272	0,001	0,000	0,000	0,001	0,000	0,000	0,000	0,008
Model	LSTR	Linear	LSTR	Linear	LSTR	ESTR	ESTR	LSTR	LSTR	LSTR	LSTR	LSTR
	Luxembourg				**Netherlands**				**Portugal**			
	π_{t-1}	π_{t-2}	π_{t-3}	π_{t-4}	π_{t-1}	π_{t-2}	π_{t-3}	π_{t-4}	π_{t-1}	π_{t-2}	π_{t-3}	π_{t-4}
H_0	0,028	0,004	0,256	0,017	0,215	0,011	0,001	0,000	0,003	0,001	0,016	0,036
H_{04}	0,207	0,000	0,501	0,008	0,464	0,349	0,495	0,010	0,058	0,045	0,489	0,228
H_{03}	0,031	0,525	0,193	0,201	0,583	0,025	0,009	0,199	0,018	0,001	0,000	0,138
H_{02}	0,197	0,450	0,286	0,456	0,042	0,025	0,001	0,000	0,000	0,000	0,000	0,000
Model	ESTR	LSTR	Linear	LSTR	Linear	ESTR	LSTR	LSTR	LSTR	LSTR	LSTR	LSTR

Note: The numbers are p-values of F versions of the LM linearity tests. First row shows the test of linearity against the alternative of STR nonlinearity. The second row until the forth are the p-values of the sequential test for choosing the adequate transition function. The decision rule is the following: if the test of H_{03} yields the strongest rejection of null hypothesis, we choose the ESTR model. Otherwise, we select the LSTR model. The last row gives the selected model.

Appendix B. Full Results from STR pass-through models

Table 3: Estimation results from LSTR model with $s_t = \pi_{t-j}$

	Austria	**Belgium**	**Germany**	**Spain**	**Finland**	**France**
s_t	π_{t-4}	π_{t-1}	π_{t-1}	π_{t-4}	π_{t-3}	π_{t-2}
c	0,033	0,030	0,013	0,022	0,027	0,011
	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)
γ	22,013	17,566	9,390	12,702	13,291	6,134
	(0,547)	(0,312)	(0,208)	(0,437)	(0,531)	(0,067)
Linear Part: $G = 0$						
Constant	0,000	0,007	0,005	0,001	0,001	0,003
	(0,866)	(0,000)	(0,000)	(0,753)	(0,485)	(0,021)
π_{t-1}			0,195			0,174
			(0,058)			(0,262)
π_{t-2}	0,160					
	(0,077)					
π_{t-3}				-0,115		
				(0,287)		
π_{t-4}	0,534	0,068	0,438	0,863	0,782	0,257
	(0,534)	(0,638)	(0,000)	(0,000)	(0,000)	(0,053)
Δe_t	0,043	0,091	0,063	0,085	0,044	0,066
	(0,042)	(0,000)	(0,000)	(0,009)	(0,005)	(0,001)
Δe_{t-1}	0,004	0,042			0,048	-0,013
	(0,821)	(0,033)			(0,002)	(0,535)
Δe_{t-2}				0,015		
				(0,626)		
Δe_{t-3}		-0,002				-0,004
		(0,845)				(0,680)
Δe_{t-4}			-0,021	0,010	-0,003	
			(0,116)	(0,567)	(0,785)	
Δw^*_t	0,078	0,140	0,091	0,171	0,058	0,111
	(0,024)	(0,000)	(0,000)	(0,003)	(0,020)	(0,002)
Δw^*_{t-1}	0,047	0,004			0,098	-0,012
	(0,213)	(0,844)			(0,000)	(0,723)
Δw^*_{t-2}		0,087	-0,001	0,040		
		(0,011)	(0,956)	(0,482)		
Δw^*_{t-3}						
Δw^*_{t-4}			-0,006			
			(0,788)			
Δy_t	0,117	-0,293		0,065	0,142	0,000
	(0,206)	(0,004)		(0,534)	(0,000)	(0,517)
Δy_{t-1}			0,026			
			(0,148)			
Δy_{t-2}	0,036					
	(0,708)					
Δy_{t-3}			-0,036			
			(0,085)			
Δy_{t-4}			0,063			
			(0,013			
Non-linear Part: $G = 1$						
Δe_t	-0,018	-0,017	-0,060	0,082	-0,024	-0,071
	(0,516)	(0,529)	(0,489)	(0,063)	(0,753)	(0,015)
Δe_{t-1}	0,071				-0,016	0,080
	(0,014)				(0,762)	(0,004)
Δe_{t-2}		-0,014		-0,097		
		(0,595)		(0,026)		
Δe_{t-3}		0,044				0,046
		(0,011)				(0,014)
Δe_{t-4}			0,110	0,057	0,120	
			(0,245)	(0,078)	(0,079)	

Key: Table reports estimates of STR pass-through equation. Numbers in parentheses are *p*-values.

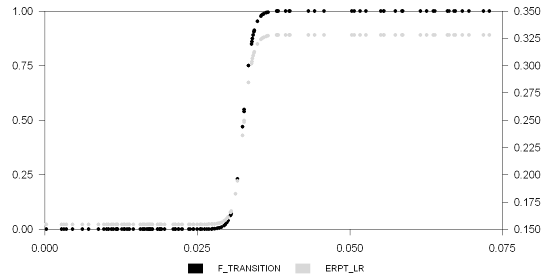
Table 3: *Continued*

	Greece	**Ireland**	**Italy**	**Luxembourg**	**Netherlands**	**Portugal**
s_t	π_{t-3}	π_{t-2}	π_{t-2}	π_{t-4}	π_{t-3}	π_{t-1}
c	0,022	0,034	0,031	0,015	0,008	0,088
	(0,024)	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)
γ	2,358	8,456	2,449	4,909	9,361	4,061
	(0,120)	(0,003)	(0,002)	(0,056)	(0,333)	(0,053)
Linear Part: $G = 0$						
Constant	-0,014	-0,001	0,002	0,002	-0,002	0,002
	(0,346)	(0,551)	(0,106)	(0,048)	(0,161)	(0,716)
π_{t-1}			0,552			0,013
			(0,000)			(0,965)
π_{t-2}		0,453		0,249	0,064	0,216
		(0,000)		(0,007)	(0,571)	(0,443)
π_{t-3}		0,092	-0,067			-0,119
		(0,250)	(0,635)			(0,702)
π_{t-4}	0,645	0,189	0,220	0,541	0,490	
	(0,000)	(0,015)	(0,096)	(0,000)	(0,000)	
Δe_t	0,105	0,043	0,032	0,053	0,049	0,040
	(0,134)	(0,097)	(0,050)	(0,002)	(0,009)	(0,547)
Δe_{t-1}	-0,046	0,074	0,021	0,039		0,001
	(0,541)	(0,003)	(0,221)	(0,012)		(0,993)
Δe_{t-2}						
Δe_{t-3}					0,010	
					(0,327)	
Δe_{t-4}						0,012
						(0,765)
Δw_t^*	0,187	0,113	0,074	0,098	0,058	0,099
	(0,036)	(0,005)	(0,007)	(0,001)	(0,072)	(0,300)
Δw_{t-1}^*	-0,029	0,139	0,025	0,059		0,011
	(0,765)	(0,000)	(0,429)	(0,020)		(0,910)
Δw_{t-2}^*						
Δw_{t-3}^*					0,001	
					(0,944)	
Δw_{t-4}^*						
Δy_t	-0,037			-0,007	-0,028	
	(0,728			(0,808)	(0,679)	
Δy_{t-1}			0,038		0,043	
			(0,616)		(0,501)	
Δy_{t-2}					0,115	
					(0,020)	
Δy_{t-3}		0,052	0,027			
		(0,298)	(0,755)			
Δy_{t-4}	-0,068	0,127			0,099	0,056
	(0,544)	(0,019)			(0,099)	(0,787)
Non-linear Part: $G = 1$						
Δe_t	-0,049	1,871	0,134	0,106	-0,013	0,045
	(0,595)	(0,001)	(0,013)	(0,008)	(0,647)	(0,609)
Δe_{t-1}	0,191	-1,355	0,078	0,023		0,165
	(0,062)	(0,018)	(0,191)	(0,531)		(0,076
Δe_{t-2}						
Δe_{t-3}					0,034	
					(0,062)	
Δe_{t-4}						0,175
						(0,005)

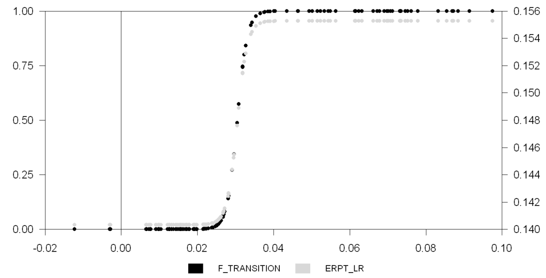
Key: Table reports estimates of STR pass-through equation. Numbers in parentheses are p-values.

Appendix C. Plots from STR pass-through equation

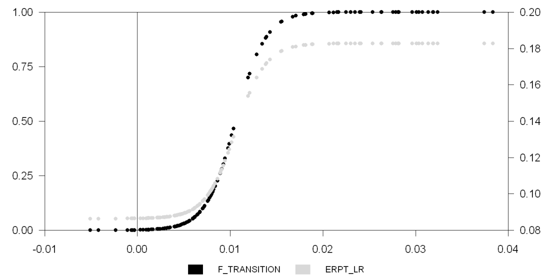
Figure 1: Estimated transition function and long-run ERPT as a function of past inflation rates



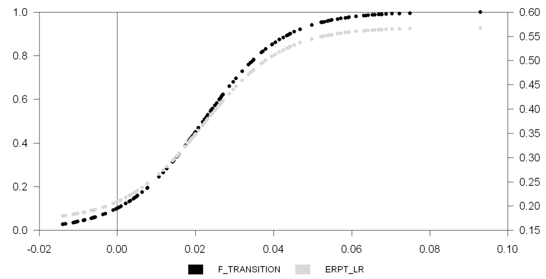
Austria



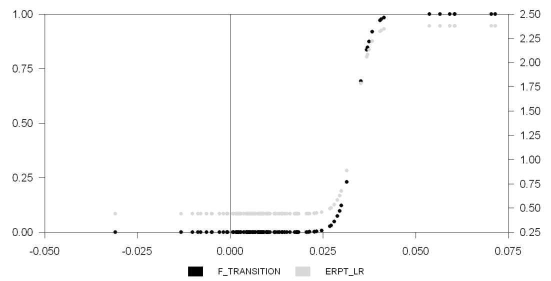
Belgium



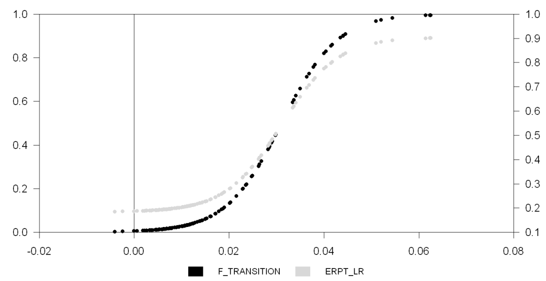
France



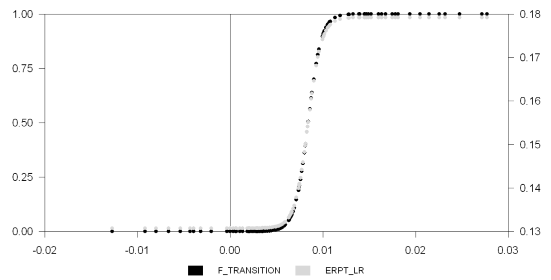
Greece



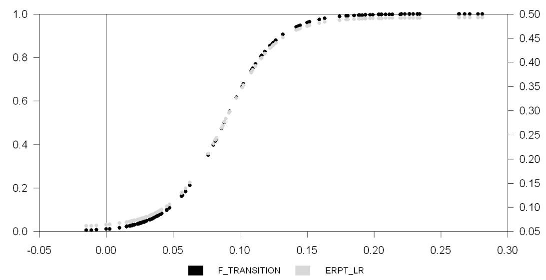
Ireland



Italy



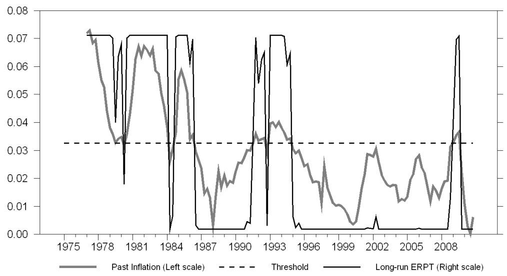
Netherlands



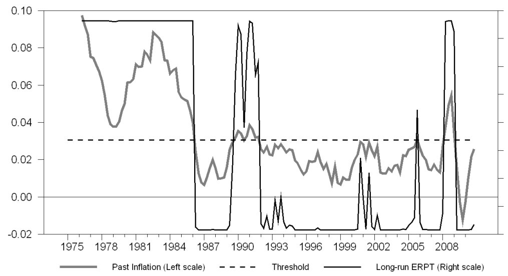
Portugal

Note: Estimated transition function and long-run ERPT as a function of past inflation rates. Results are from LSTR with $s_t = \pi_{t-j}$.

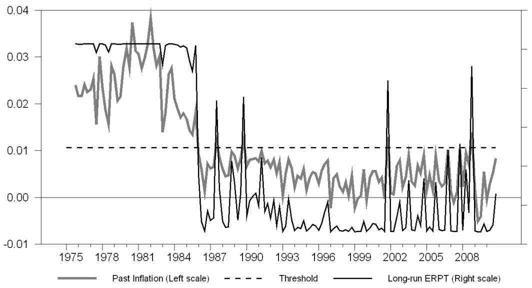
Figure 2: Time-varying long-run ERPT and past inflation over 1975-2010



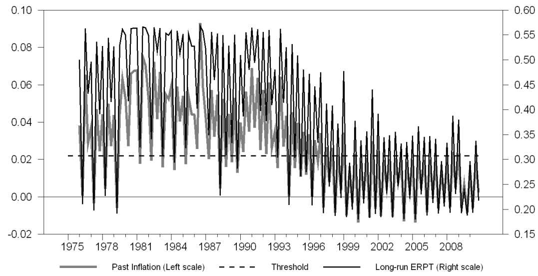
Austria



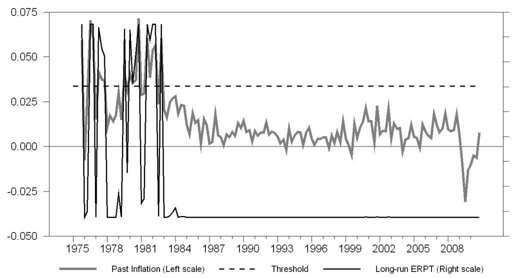
Belgium



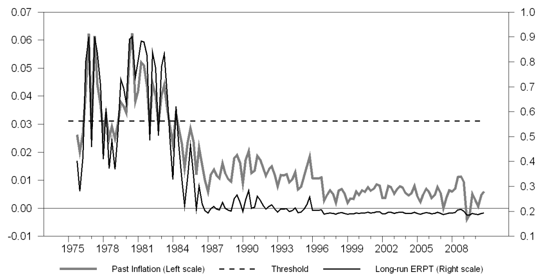
France



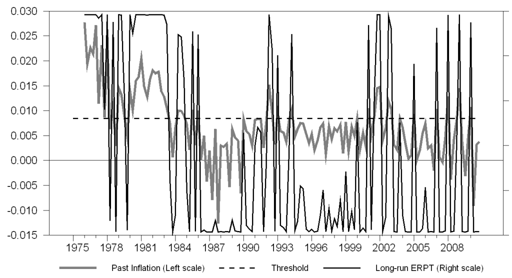
Greece



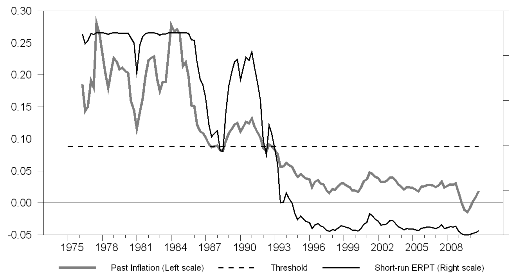
Ireland



Italy



Netherlands



Portugal

Note: Time-varying long-run ERPT and past inflation during 1975-2010. Results are from LSTR model with $s_t = \pi_{t-j}$.