Asymmetric Exchange Rate Pass-Through in the Euro Area: New Evidence from Smooth Transition Models

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Abstract   This paper examines the presence of asymmetric behavior in exchange rate pass-through (ERPT) to CPI inflation in 12 euro area (EA) countries. Using a class of nonlinear smooth transition models, we test for asymmetry with respect to the direction and the magnitude of exchange rate changes. On the one hand, we find only 5 out of 12 EA countries showing asymmetric pass-through to exchange rate appreciations and depreciations. Results are somewhat mixed with no clear evidence about the direction of asymmetry. On the other hand, we report strong evidence that ERPT responds asymmetrically to the size of exchange rate changes as a result of presence of menu costs. The degree of ERPT is found to be higher for large exchange rate changes than for small ones in 9 out of 12 EA countries.

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1 Introduction

The issue of asymmetries and nonlinearities is one of the burgeoning topics in the literature of Exchange Rate Pass-Through (ERPT)[1]. There are various circumstances that could generate asymmetric adjustment of prices to exchange rate changes which can't be modeled within a simple linear framework. Some spectacular exchange rate movements like those experienced by the US dollar in the 1980s seems to be a good illustration of the existence of an asymmetric behavior in ERPT. At that time, the appreciation of the dollar against the Deutsch mark amounted to 70% between 1980-1985 and the subsequent depreciation amounted to 80% by the end of 1987. Similarly, at the launch the creation of the euro area (EA), there has been a large depreciation of the European currency against the US dollar from 1999 till the last of 2001. After that date, the euro started appreciating to become a strong and well established currency. It is expectable that these dramatic exchange rate developments may affect asymmetrically domestic prices, raising the question of the presence of a nonlinear dynamic in ERPT mechanism (see Bussière (2007))[2].

Nonetheless, the empirical literature has paid little attention to the issue of asymmetries and nonlinearities in ERPT in spite of its strong policy relevance. The number of studies which have investigating for nonlinearities in this context is to date relatively scarce, and most of papers assume linearity rather than testing it. The sparse empirical evidence on this area of research has put forth the role of exchange rate movements in generating nonlinearities. According to this literature, there mainly two potential sources of pass-through asymmetry[3]. In one hand, potential pass-through asymmetries can arise from the *direction* of exchange rate changes i.e., in response to currency depreciations and appreciations. In the other hand, the extent of pass-through may also respond asymmetrically to the *magnitude* of exchange rate movements, i.e. depending on whether exchange rate changes are large or small. However, as pointed by Marazzi et al. (2005), previous studies provide mixed results with no clear support for the existence of important asymmetries or nonlinearities. If the existing literature is not conclusive, there is an important caveat that should be noted in this regard which is related to the econometric specification. Several empirical studies on asymmetries in ERPT experiment a

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[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] Mussa (2005) argued that the large movement of the exchange rate of the US dollar against euro area currencies in 1980-1987 was significantly larger than the huge swing in the euro/dollar exchange rate since the beginning of 1999.

[3] There are other factors that could generate asymmetry in the pass-through mechanisms. For instance, Goldfajn and Werlang (2000) report an asymmetric reaction of the ERPT over the business cycle.

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 (See Yang (2007)). For Example, in order to capture possible asymmetries in ERPT, Coughlin and Pollard (2004) use threshold dummy variables to distinguish between large and small exchange rate changes. The authors choose an arbitrary threshold value for all US industries equal to 3%. A large exchange rate change is defined as being 3% and above, while a small change is below 3%. However, for more accuracy, the threshold level must be estimated from the data instead of using an arbitrary value. So, a relevant econometric methods is required. An alternative methodology is to estimate a nonlinear regime-switching model where a grid search is used to select the appropriate threshold. Amongst this class of models, two popular nonlinear models can be mentioned. First, the so-called threshold regression model where the transition across regimes is abrupt[4]. Second, the smooth transition regression (STR) model with the transition between states is rather smooth[5]. In our paper, we propose to use the second type of regime-switching model, namely a class of smooth transition regression models, in order to investigate for the presence of an asymmetric mechanism in the ERPT.

To our knowledge, there are only two studies that found an asymmetric ERPT using a smooth nonlinear regression. Shintani et al. (2009) estimated the ERPT to US domestic prices with respect to inflation regime. They find that the period of low ERPT would be associated with the low inflation environment. In a more complete study, Nogueira Jr. and Leon-Ledesma (2008) examine the possibility of nonlinear pass-through for a set of inflation target countries. They found that ERPT respond nonlinearly to several macroeconomic factors, including inflation rate, the size of exchange rate changes, macroeconomic instability and output growth[6]. Therefore, our paper aims at contributing to fill the gap in empirical evidence on the nonlinearities in ERPT. We focus on "consumer-price pass-through", i.e. the sensitivity of consumer prices to exchange rate changes. Our study is close to Nogueira Jr. and Leon-Ledesma (2008) who examined the role of the size of the exchange rate movements in generating asymmetry by implementing an exponential STR model. However, in our work, we aim to explore the two possible sources of asymmetries in ERPT, i.e. with respect to both *direction* and *size* of exchange rate changes. Also, unlike Nogueira Jr. and Leon-Ledesma (2008), we are interested in the euro area (EA) case since we expect that the different exchange rate arrangements experienced by the monetary union members would generate

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[4] The univariate case is known as the threshold autoregressive (TAR) Model.

[5] The univariate case is known as smooth transition autoregressive (STAR) Model.

[6] Herzberg et al. (2003) analyzed the ERPT into UK import prices using a STR model but did not find any evidence of nonlinearity.

a nonlinear mechanism in ERPT. To the best of our knowledge, there is no other study has applied a nonlinear STR estimation approach in this context.

The remainder of the paper is organized as follows. Section 2 gives some arguments that justify the existence of asymmetric pass-through and discusses the analytical framework that underlies this dynamic behavior. In section 3, the empirical specification is presented. Section 4 gives the main empirical results and Section 6 concludes.

2   ERPT and nonlinearities

2.1   Why ERPT would be asymmetric?

From theoretical point of view, the assumption that ERPT is linear and symmetric is not realistic. In fact, there are various circumstances that could generate asymmetry in the pass-through mechanisms. Despite its policy relevance, studies dealing with this issue are still relatively scarce. The sparse empirical evidence on this area of research has put forth the role of exchange rate movements in generating nonlinearities. In one hand, asymmetric behavior can arise from the *direction* of exchange rate changes i.e., in response to currency depreciations and appreciations (see e.g. Gil-Pareja (2000)). In the other hand, the extent of pass-through may also respond asymmetrically to the *magnitude* of exchange rate movements, since there is differential effect of large versus small exchange rate changes (see e.g. Coughlin and Pollard (2004)). There is some theoretical (microeconomic) arguments behind the potential asymmetric relationship between the exchange rate and prices. Mainly, we mention the three major explanations of a possible ERPT asymmetry:

- *Market share objective*: faced with a depreciation of the importing country's currency, foreign firms can follow pricing-to-market (PTM) strategy by adjusting their markups to maintain market. However, with an appreciation, they maintain their markups and allow the import price to fall in the currency of destination market. Consequently, the extent of ERPT would be different with respect to exchange rate change direction. If firms attempt to keep competitiveness and maintain market share, then an appreciation of the importing country's currency might cause higher pass-through than a depreciation.

- *Capacity constraints*: quantities may be rigid upwards in the short run. Faced with a currency's importing country appreciation, exporters would gain in price competitiveness by passing this exchange rate change into their prices. But, if firms have already reached full capacity, the ability of increasing sales in destination market is limited, and they may be tempted to increase their

mark-up instead of lowering prices in importer's currency[7]. As argued by
Knetter (1994), if exporting firms are subject to binding *quantity constraints*,
then an appreciation of the currency of the importing country might cause
lower pass-through than a depreciation.

It is important to note that these two first arguments have a clear implication
for possible non-linearities in ERPT, but in the same time they give rise to opposite
interpretations of asymmetry. According to market share explanation, pass-through
will be higher when the importer's currency is appreciating than when it is depreci-
ating. While, the quantity constraint hypothesis suggest the opposite result, and
ERPT would be highest when exchange rate is depreciating. Empirically, previous
studies provide no clear evidence on the direction of asymmetry. In some cases
the pass-through associated with depreciations exceeded appreciations; however,
in other cases, this result is rather the opposite. Gil-Pareja (2000) analyzed the
differences in pass-through in a set of industries across a sample of European
countries. He found that the direction of asymmetry varied across industries and
countries. According to Coughlin and Pollard (2004), the contrasting direction of
the asymmetry highlights the importance of analyzing pass-through at the industry
level. If the direction of asymmetry varies across industries then aggregation may
obscure asymmetry that is present at the industry level.

Finally, the third potential source of nonlinearities is relative to *menu costs*.

- *Menu Costs*: because of the costs associated with changing a price, exporters
  may leave their price in importer's currency unchanged if exchange rate
  changes are small. However, when exchange rate changes exceed some
  threshold i.e., with large magnitude, firms do change their prices. Thus,
  according to menu costs hypothesis, ERPT may be asymmetric with respect
  to the size of the exchange rate shocks, since price adjustment is more
  frequent with large exchange rate changes than with small ones.

This latter asymmetric dynamic behavior has been put forth empirically by
Coughlin and Pollard (2004). In their study on U.S. import prices of 30 industries,
they found that most firms respond asymmetrically to large and small changes
in the exchange rate with ERPT positively related to the size of the change. It is
noteworthy that Coughlin and Pollard (2004) use threshold dummy variables to
distinguish between large and small exchange rate changes, in order to capture a
possible asymmetric behavior in pass-through mechanism. The authors choose an
arbitrary threshold value for 30 US industries to distinguish between small and
large exchange rate changes. The latter is defined as a change greater than 3%. In

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[7] Capacity constraints may also arise because of trade restrictions that limit imports, such as quotas
or voluntary export restraints (see Coughlin and Pollard (2004)).

our paper, unlike Coughlin and Pollard (2004), we propose to estimate a nonlinear smooth transition model where a grid search is used to select the appropriate threshold level instead of using an arbitrary threshold value.

2.2 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, P_i, set in importing country currency, yield the following expression:

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

Where E is the exchange rate measured in units of the importer 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 and 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 and Knetter (1997))[8]:

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

From equation (2), the ERPT coefficient is given by 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 fact, pricing strategies of firms depend not solely on demand conditions in the market. We suggest that foreign firm would adjust prices with respect to the magnitude or the direction of exchange rate movements. As mentioned above, exporters may leave their price unchanged if exchange rate changes are small due to the presence of menu costs. They change their prices only when the exchange rate change is above a given threshold. Thus, there

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

will be differential effect of large versus small exchange rate changes on ERPT. Similarly, if firms attempt to keep competitiveness, faced with a depreciation of the importer currency, they tend to adjust markups to maintain market. Then an appreciation of the importing country's currency might cause higher pass-through than a depreciation. We have seen above that this latter result may be reversed when foreign firms are subject to *capacity constraints* in the short run, then an appreciation of the currency of the importing country might cause lower pass-through than a depreciation.

Consequently, we assume that pricing strategy of foreign firms to depend on the magnitude and the direction of exchange rate changes in a nonlinear framework. We consider $\kappa(\Delta e)$ as a function that captures the size or the direction of exchange rate changes. This can be seen as a firms' strategic decision on how much to adjust price in importer's currency given the size or the direction of exchange rate movements. Taking into account this factor, we can rewrite foreign firm markup as follow:

$$\mu_i = \mu(Y, E^{\kappa(\Delta e)}), \tag{3}$$

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

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

According to the function $\kappa(\Delta e)$, there is an indirect channel of pass-through which depends on the extent of currency movements which is assumed to affect firm's markup in a nonlinear way. We consequently consider that there is some exchange rate changes threshold level Δe^* which provides two extreme regimes:

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

According to (4) and (5), the degree of pass-through would be different and depends on whether the exchange rate changes is above or below a threshold level. Here the extent of ERPT would be different with respect to the size of exchange rate change, i.e. to large and small exchange rate changes. If the importer's currency changes are below some threshold ($\Delta e \leq \Delta e^*$), then ERPT would be equal to β. While for large exchange rate movements ($\Delta e > \Delta e^*$), then ERPT becomes ($\beta + \phi$). Similarly, when the threshold level is close to zero ($\Delta e^* \simeq 0$), this pattern (equation (4) and (5)) can describe asymmetric ERPT with respect to the direction of exchange rate. Therefore, when exchange rate is appreciating ($\Delta e < 0$), the

degree of pass-through would be equal to β, and when is depreciating ($\Delta e > 0$), ERPT corresponds to ($\beta + \phi$). The advantage of equation (4) is to describe this changing behavior in pass-through in a nonlinear fashion. Then, we expect that price responsiveness to be different with respect to the size and the direction of exchange rate changes. Finally, it should be noted that the transition from one regime to the other is assumed to be smooth.

3 Empirical approach

3.1 Smooth transition regression models

To capture nonlinearity 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 $u_t \sim iid(0, \sigma^2)$, $\mathbf{z}_t = (\mathbf{w}_t', \mathbf{x}_t')'$ 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[9]. 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 ($s_t = x_{kt}$).

There are two popular choices for the transition function:

- Logistic Function

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

- Exponential Function

$$G(s_t; \gamma, c) = 1 - \exp\{-\gamma(s_t - c)^2\} \tag{8}$$

Equations (6) and (7) jointly define the logistic STR (LSTR) model and the pattern formed jointly by (6) and (8) is called the exponential STR (ESTR) model. In Both models, the parameter c can be interpreted as the threshold between two extremes regimes $G(s_t; \gamma, c) = 0$ and $G(s_t; \gamma, c) = 1$. For the LSTR model, the nonlinear coefficients would take different values depending on whether

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

the transition variable is below or above the threshold. So, the parameters $\phi + \theta G(s_t; \gamma, c)$ 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 $s_t = c$, then $G(s_t; \gamma, c) = 1/2$ and coefficients will be $(\beta + \phi/2)$.

Concerning ESTR model, this specification is appropriate in situations in which the dynamic behavior is different for large and small values of s_t; what matters is the magnitude of shocks, if they are large or small. In other words, the coefficient changes depending on whether s_t is near or far away from the threshold, regardless of whether this difference $(s_t - c)$ is positive or negative. Therefore, the exponential transition function $G(s_t; \gamma, c) \to 1$ as $(s_t - c) \to \pm\infty$, and then coefficients of the model will be equal $(\beta + \phi)$. If $s_t = c$, then $G(s_t; \gamma, c) = 0$ and coefficients becomes β.

The implied nonlinear dynamics under logistic and exponential functions are drastically different. LSTR model is pertinent in describing asymmetric dynamic behavior between negative or positive deviations of the transition variable s_t from the threshold level c. As mentioned in the STR literature (van Dijk et al. (2002)), when modeling business cycle, LSTR can describe processes whose dynamic properties are different in expansions from what they are in recessions. For example, if the transition variable s_t is a business cycle indicator (such as output growth), and if $c \simeq 0$, the model distinguishes between periods of positive and negative growth, that is, between expansions and contractions. On the other hand, an ESTR allow for symmetric dynamics with respect to negative or positive deviations of s_t from the threshold level. The function rather depends on whether the transition variable is close or far away from the threshold c. Exponential specification was popularly employed in analyzing the nonlinear adjustment of real exchange rates (see e.g. Taylor et al. (2001)).

Since LSTR and ESTR models would allow for different nonlinear behavior, we must be careful in our implementation of these specifications in our ERPT analysis. When we consider exchange rate as transition variable, LSTR model can account for asymmetric ERPT during currency appreciations and depreciations, i.e. with respect to the *direction* of exchange rate changes[10]. For ESTR model, the interpretation is different, and what matters is the *magnitude* of exchange rate changes, i.e. whether exchange rate changes are large or small. According to ERPT literature, firms are willing to absorb small changes in exchange rate rather than larger ones due to the presence of *menu costs*. Thus, the costs of changing prices may result in asymmetric pass-through for large and small exchange rate shocks. ESTR specification would be more appropriate in describing this kind of behavior as argued by Nogueira Jr. and Leon-Ledesma (2008). It is important to

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[10] Especially, when the threshold value is close to zero ($c \simeq 0$)

note that choosing the relevant transition function can be conducted together with nonlinearity specification tests in addition to the economic intuition (more details in section 4).

As discussed in Teräsvirta (1994), the modelling strategy of STR models follows three stages: specification, estimation, and evaluation. The first stage consists in testing for nonlinearity and choosing the appropriate threshold variable $(s_t = \Delta e_{t-j})$ and the most suitable form of the transition function, i.e. logistic or exponential specification[11]. In the second stage, the parameters of the STR model are estimated by nonlinear least squares (NLS) estimation technique which provides estimators that are consistent and asymptotically normal. 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[12]. 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 and Terasvirta (1996) suggested two additional LM-type misspecification tests: an LM test of no remaining nonlinearity and LM-type test of parameter constancy.

3.2 Model specification and data

In our empirical analysis, we define a *STR pass-through* equation which is derived from the theoretical model (4). It consists of an extension of Campa and Goldberg (2005) pass-through model to nonlinear case. Then, the equation to estimate has the following form:

$$
\begin{aligned}
\pi_t = \alpha + \sum_{j=0}^{N} \beta_j \Delta e_{t-j} + \left(\sum_{j=0}^{N} \phi_j \Delta e_{t-j} \right) G(s_t; \gamma, c) \\
+ \sum_{j=0}^{N} \psi_j \Delta y_{t-j} + \sum_{j=0}^{N} \delta_j \Delta w_{t-j}^* + \varepsilon_t,
\end{aligned}
\tag{9}
$$

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

[12] 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.

Where π_t is the CPI inflation rate, Δe_t is the rate of depreciation of the nominal effective exchange rate, Δy_t is the output growth and Δw_t^* is the changes in foreign producer cost. $G(s_t; \gamma, c)$ is the logistic transition function driving the nonlinear dynamic. We consider the lagged exchange rate depreciation as transition variable $s_t = \Delta e_{t-j}$. According to (9), the degree of ERPT is given by the following time-varying coefficients:

$$ERPT = \beta_0 + \phi_0 G(s_t; \gamma, c) \tag{10}$$

For the LSTR model, ERPT coefficient would take different values depending on whether the transition variable is below or above the threshold. If $(\Delta e_t - c) \to -\infty$, pass-through elasticity corresponds to: ERPT= β_0. If $(\Delta e_t - c) \to +\infty$, pass-through coefficient becomes: ERPT= $\beta_0 + \phi_0$. In the case of the ESTR model, pass-through elasticities change depending on whether Δe_t is near or far away from the threshold c, regardless of whether the difference $(\Delta e_t - c)$ is positive or negative. Therefore, if $(\Delta e_t - c) \to \pm\infty$, ERPT is equal to $\beta_0 + \phi_0$; and if $\Delta e_t = c$, pass-through elasticity becomes = β_0.[13]

The STR pass-through equation (9) 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 and 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[14]. To determine the lag length of the variables, we follow van

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[13] We can define the long-run ERPT as the sum of the linear and nonlinear parts of the model: $\sum_{j=0}^{N} \beta_j + \sum_{j=0}^{N} \phi_j G(s_t; \gamma, c)$. This definition of long-run pass-through was severely criticized by de Bandt et al. (2008). The authors point out that this measure is very sensitive to the number of lags introduced in the model, leading to inaccurate long-run effect.

[14] 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 (9). Augmented Dickey Fuller (ADF) tests suggest that variables in differences are appropriately described as stationary series.

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.

4   Main Empirical Results

In this section we investigate the presence of asymmetric behavior in ERPT mechanism for 12 EA countries. As discussed above, there are two types of asymmetries that can be modeled with nonlinear STR models. In one hand, pass-through asymmetries may arise with respect to exchange rate change *direction* i.e., in response to currency depreciations and appreciations. In the other hand, there is a second type of asymmetry which is related to the *size* of exchange rate movements, since pass-through could be greater when exchange rate changes are large than when they are small. Consequently, the rate of exchange rate depreciation (Δe_{t-i}) is considered as the driving factor of the nonlinearity in STR models.

We begin by choosing the relevant transition variable by means of linearity tests as reported in Table 3 in Appendix A. The linearity tests are conducted for each lagged rate of depreciation Δe_{t-j} with $j = 1, 2, 3, 4$. Also, no remaining nonlinearity tests are conducted after estimation in our choice of transition variable. We select the transition variables that provided the strongest rejection of both the null of linearity of the baseline linear model, and of no additive nonlinearity after estimation of the nonlinear model. According to Table 3, there is an evidence of presence of nonlinearity in all EA countries expect for Austria. Once linearity has been rejected, we employ the sequence of null hypotheses for selecting the relevant transition function, i.e. logistic or exponential (see Appendix A for details). As discussed in van Dijk et al. (2002), recent increases in computational power have made the decision rule, based on testing a sequence of nested null hypotheses, less important in practice. The authors argued that is easy to estimate a number of both LSTAR and ESTAR models and choose between them at the evaluation stage by misspecification tests. In addition, economic intuition must be considered in selecting the adequate transition function. In their study, Nogueira Jr. and Leon-Ledesma (2008) examined the role of the size of the exchange rate movements in generating asymmetry by implementing an ESTR specification. However, in our work, we aim to explore the two possible sources of nonlinearities in ERPT, i.e. with respect to both direction and magnitude of exchange rate changes. Therefore, we follow van Dijk et al. (2002) approach by estimating a number of both LSTAR and ESTAR models for each country. This is a sensible way to check what kind of asymmetry that really drives the nonlinear mechanism in ERPT. As explained in section 3, LSTR specification is appropriate to capture asymmetry arising from the

direction of exchange rate changes, while ESTR specification is more suitable for asymmetric behavior with respect to the size of exchange rate movements.

4.1 Results from LSTR model

The NLS estimates of *LSTR pass-through* equation are summarized in Table 1. We report 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 (10). Full results from all STR models are presented in Table 4 in Appendix C. We compute sum of squared residuals ratio (SSR_{ratio}) between LSTR model and the linear specification which suggests a better fit for the nonlinear 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. In Table 1, we give only results for countries with significant nonlinear mechanisms. We note that there are only 5 out of 12 EA countries showing a significant response of CPI inflation to exchange rate movements in a nonlinear way. The threshold levels are quite similar for Italy, Luxembourg and Portugal (around 4%), but differ greatly in comparison to Belgium and Greece. We have plotted both the estimated transition functions and the ERPT as a function of the lagged transition variable ($s_t = \Delta e_{t-i}$) in Figure 1 in Appendix B. It is clear that the transition between both extreme regimes ($G = 0$ and $G = 1$), is smooth in most of cases, except for Belgium where γ is very high indicating a rather abrupt transition[15]. Concerning ERPT estimates, our results are to some extent mixed. For Italy, Luxembourg and Portugal, when exchange rate is depreciating above some threshold level, the degree of pass-through becomes higher. For example, ERPT coefficient rise from 0.07% to 0.27% in Portugal once the rate of currency depreciation is exceeding 4.5%. We can say that exchange rate transmission is higher for large rate of depreciation, but it becomes lower for small depreciation and when currency is appreciating. These results seem to be consistent with the so-called *capacity constraints* hypothesis. This latter stipulates that a depreciation of the importer's currency would cause higher pass-through than an appreciation. Since quantities may be rigid upwards in the short run, exporters may not be able to increase sales when importing country currency is appreciating. So, they are willing to raise markup leaving quantity and price unchanged in importing country. In this case, pass-through would be greater when the importer's currency is depreciating than when it is appreciating.

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[15] 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 LSTR model

	Belgium	Greece	Italy	Luxembourg	Portugal
Transition variable (s_t)	Δe_{t-4}	Δe_{t-4}	Δe_{t-2}	Δe_{t-1}	Δe_{t-1}
Threshold (c)	0,004	-0,021	0,044	0,037	0,045
	(0,050)	(0,000)	(0,000)	(0,000)	(0,000)
Speed of transition (γ)	60,750	9,675	7,513	18,530	5,317
	(0,555)	(0,262)	(0,095)	(0,379)	(0,029)
Linear Part : $G=0$					
ERPT	0,101	0,196	0,036	0,060	0,069
	(0,000)	(0,033)	(0,030)	(0,000)	(0,131)
Non-linear part : $G=1$					
ERPT	0,041	0,049	0,101	0,123	0,272
	(0,016)	(0,081)	(0,106)	(0,001)	(0,000)
R^2	0,723	0,904	0,911	0,751	0,805
SSR_{ratio}	0,828	0,634	0,803	0,778	0,694
pJB	0,718	0,000	0,000	0,026	0,001
$pLM_{AR(4)}$	0,436	0,094	0,977	0,876	0,315
$pLM_{ARCH(4)}$	0,625	0,440	0,008	0,867	0,005
pLM_C	0,165	0,303	0,020	0,137	0,012
pLM_{NLR}	0,069	0,154	0,548	0,416	0,168

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 and SSR_{ratio} is the ratio of sum of squared residuals between LSTR model and the linear specification. 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.

However, results are quite different for Belgium and Greece. The response of CPI inflation to exchange rate is negatively correlated with the rate of depreciation (See Figure 1 in Appendix B). For Belgium, ERPT decreases significantly from 0.1% to 0.04% as the exchange rate is depreciating. Since the threshold level is close to zero ($c = 0.004$), we can say that the extent of pass-through is smaller during the depreciation than in appreciation episodes. This is in line with the thesis of *Market share objective*. Faced with a depreciation of the importing country's currency, foreign firms can follow pricing-to-market strategy by adjusting their markups to maintain market. But in the case of an appreciation, they maintain their markups and allow the import price to fall in the currency of destination market. Consequently, an appreciation of the importing country's currency might cause larger pass-through than depreciation.

In all, our results are somewhat mixed since there is no clear direction of asymmetry. For 3 out of 5 EA countries (Italy, Luxembourg and Portugal), ERPT is greater when exchange rate is depreciating, while for Belgium and Greece, pass-through is lower when importer's currency is depreciating. Nevertheless, our findings corroborate with previous empirical studies which provide also no clear evidence on the direction of asymmetry in ERPT. For a set of European industries, Gil-Pareja (2000) found that the direction of the asymmetry varied across industries and countries. Coughlin and Pollard (2004) confirm the same results in their study on 30 U.S. industries.

4.2   Results from ESTR model

The second potential source of nonlinearity is related to the magnitude of exchange rate change. In other words, what matters is if exchange rate movements are large or small. As discussed above, an ESTR specification would be more appropriate to capture this kind of asymmetry since dynamic must be different whether Δe_{t-i} is close or far away from a certain threshold. As we can see in Table 2, most of EA countries (except Austria and Portugal) exhibit a significant nonlinear dynamic behavior with respect to the size of exchange rate changes[16]. Our results provide an evidence of positive correlation between pass-through and the magnitude of currency changes for 9 EA countries[17]. For instance, the ERPT coefficient in Spain is not significantly different from zero when exchange rate variation is small, i.e. Δe_{t-i} is close to the threshold of $c = 0.006$. But for large currency movements, when Δe_{t-i} is far away from the threshold level, the Spanish pass-through corresponds to 0.12%.

Figure 2 in appendix B gives a supportive evidence of the presence of asymmetries arising from the size of exchange rate shocks. That is, large exchange rate changes elicit greater ERPT. This result is consistent with the *menu costs* assumption. If foreign firms perceive that price changes are costly, a small currency change can be accommodated within the markup. But, if exchange rate changes exceed some threshold, firms are tempted to change their prices in the currency of importing country. Empirically, Nogueira Jr. and Leon-Ledesma (2008) has put forth the role of menu costs in explaining nonlinearities in ERPT. To the best of our knowledge, it is the only work using ESTR model in this context. The results of Nogueira Jr. and Leon-Ledesma (2008) suggest that only two out of six countries (Mexico and UK) provide an evidence of nonlinear ERPT with respect to the size of exchange rate changes.

To give further insight on the relationship between pass-through and the magnitude of exchange rate changes, we plot the time-varying ERPT coefficients over the period 1975-2010 (see Figure 3 in Appendix B). We also report lagged exchange rate depreciation and the threshold value on the same graph. An interesting result concern the period of launching the euro area. It is well-known that the EA countries - except Greece that joined the monetary union in 2001 - have experienced an ongoing depreciation of the euro between the end of 1998 until the last quarter of 2001[18]. While, since the mid-2002, the euro has started a steady appreciation until the end of 2004.

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[16] In Table 2, we report results only for countries with a significant nonlinear mechanisms.

[17] For Ireland, there is an evidence of presence of nonlinear mechanisms (significant threshold value and speed of transition) but ERPT coefficient is not significant.

[18] During this period, the euro has depreciated by nearly 20% in nominal effective terms.

Table 2: Estimated ERPT elasticities from the ESTR model

	Belgium	Germany	Spain	Finland	France	Greece	Ireland	Italy	Luxembourg	Netherlands
Transition variable (s_t)	Δe_{t-4}	Δe_{t-1}	Δe_{t-4}	Δe_{t-2}	Δe_{t-3}	Δe_{t-3}	Δe_{t-2}	Δe_{t-1}	Δe_{t-3}	Δe_{t-4}
Threshold (c)	0,022	0,006	0,035	0,021	-0,022	0,030	0,043	0,016	0,010	0,033
	(0,059)	(0,037)	(0,004)	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)	(0,016)	(0,000)
Speed of transition (γ)	4,381	11,092	4,322	11,347	2,487	33,264	1,274	9,112	4,041	1,128
	(0,000)	(0,062)	(0,110)	(0,004)	(0,064)	(0,053)	(0,025)	(0,105)	(0,057)	(0,058)
Linear part : $G = 0$										
ERPT	-0,016	0,002	0,019	-0,071	-0,019	-0,291	0,065	0,009	0,055	-0,018
	(0,681)	(0,972)	(0,814)	(0,183)	(0,485)	(0,073)	(0,256)	(0,886)	(0,062)	(0,476)
Non-linear part: $G = 1$										
ERPT	0,103	0,075	0,121	0,050	0,077	0,104	-0,010	0,070	0,090	0,104
	(0,000)	(0,000)	(0,000)	(0,004)	(0,000)	(0,000)	(0,750)	(0,000)	(0,000)	(0,000)
R^2	0,660	0,573	0,787	0,796	0,884	0,882	0,802	0,902	0,742	0,737
SSR	0,826	1,147	1,020	0,768	0,962	0,781	0,685	0,886	0,807	0,827
pJB	0,229	0,000	0,000	0,035	0,002	0,450	0,000	0,000	0,132	0,464
$pLM_{AR(4)}$	0,454	0,000	0,582	0,043	0,000	0,000	0,123	0,147	0,834	0,850
$pLM_{ARCH(4)}$	0,340	0,801	0,521	0,010	0,640	0,000	0,154	0,389	0,224	0,293
pLM_C	0,070	0,605	0,137	0,131	0,166	0,450	0,456	0,037	0,253	0,207
pLM_{NLR}	0,113	0,199	0,370	0,368	0,572	0,659	0,107	0,328	0,220	0,253

Note: Table reports elasticities of exchange rate pass-through into CPI inflation from ESTR models. Numbers in parentheses are *p*-values of estimates. R^2 denotes the coefficient of determination and SSR_{ratio} is the ratio of sum of squared residuals between ESTR model and the linear specification. 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.

As argued by Bussière (2007), such dramatic changes in the value of European currency may give rise to asymmetric pass-through. Thereby, it is clear from the visualization of Figure 3 that ERPT was higher following the introduction of the euro for most of our EA countries. According to our results, the dramatic change of the European currency during the three first years of the euro has elicited a higher rate of pass-through. When the depreciation of the euro surpassed some limit, those countries have experienced a higher response of CPI inflation which can be interpreted as a proof of nonlinear mechanisms of pass-through.

Also, another prominent result is relative to the European Monetary System (EMS) crisis (1992-1993). During this episode, the extent of pass-through was higher for most of EA countries. It is known that for members of EMS, currencies were allowed to fluctuate within pre-specified bands (a system known as the Exchange Rate Mechanism (ERM)). During the crisis period, a wave of devaluations has occurred for major EMS countries, especially for Italy that was forced to withdraw the ERM in September 1992[19]. Consequently, due to the excessive variability of the European currencies (conjugated with confidence crisis), it is expected that foreign firms tend to modify pricing strategy, shifting from importer's currency pricing (*LCP* strategy) to exporter's currency invoicing (*PCP* strategy). As a result, the degree of pass-through is found to be higher during this episode. Similarly, one might say that the EMS crisis could be an illustration of asymmetric mechanisms of ERPT with respect to the magnitude of exchange rate change. When exchange rate changes surpass some limit, the exchange rate transmission becomes larger.

5   Conclusion

In this study, we investigate for possible nonlinear mechanisms in the ERPT to consumer prices for 12 EA countries. This exercise is conducted using the family of smooth transition regression models as a tool. Using quarterly data spanning from 1975 to 2010, we explore the existence of nonlinearities with respect to the direction and the size of exchange rate changes. First, we provide a support of asymmetrical ERPT to appreciations and depreciations, but there is no clear-cut about the direction of asymmetry. In other words, for some countries pass-through is found to be greater when exchange rate is depreciating than when it is appreciating. This finding is consistent with the so-called *quantity constraint* theory. Nevertheless, we find the opposite result for the rest of EA countries, i.e. ERPT is higher during importer's currency appreciation than during a period of depreciation. This latter result is line with the *market share* explanation. It is important to note that similar mixed result was pointed out by a number of empirical

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[19] Austria, Finland and Greece were not member of the ERM at that time.

studies (Gil-Pareja (2000) and Coughlin and Pollard (2004)). Next, we check the asymmetry of pass-through with respect exchange rate magnitude. CPI inflation reaction is found to be higher for large exchange rate changes than for small ones. This can be interpreted as an evidence of the presence of *menu costs*, where large currency movements are promptly transmitted to prices. A careful inspection of time-varying pass-through elasticities reveals that CPI inflation responsiveness to exchange rate variation was relatively higher during the EMS Crisis and at the launch of the euro.

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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:

$$y_t = \alpha_0' \mathbf{z}_t + \sum_{j=1}^{3} \alpha_j' \tilde{\mathbf{z}}_t s_t^j + u_t^*, \quad t = 1,...,T, \tag{11}$$

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 (see 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 (11). 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. Tables (3) provides the p-values of the F version of the LM test with the different lags for the inflation rate. In the first row, we report the test of the null hypothesis of linearity against the alternative of STR non-linear model. The following rows in each table show the sequence of null hypotheses for choosing the LSTR or the ESTR model.

Table 3: Linearity tests against STR model with $s_t = \Delta e_{t-j}$

	Austria				Belgium				Germany			
	Δe_{t-1}	Δe_{t-2}	Δe_{t-3}	Δe_{t-4}	Δe_{t-1}	Δe_{t-2}	Δe_{t-3}	Δe_{t-4}	Δe_{t-1}	Δe_{t-2}	Δe_{t-3}	bf Δe_{t-4}
H_0	0,975	0,116	0,933	0,943	0,001	0,149	0,226	0,162	0,018	0,000	0,956	0,120
H_{04}	0,987	0,311	0,990	0,965	0,014	0,258	0,913	0,028	0,060	0,088	0,978	0,469
H_{03}	0,647	0,088	0,986	0,734	0,605	0,421	0,766	0,763	0,299	0,285	0,917	0,027
H_{01}	0,754	0,329	0,101	0,529	0,001	0,108	0,002	0,476	0,042	0,000	0,298	0,488
Specification	Linear	Linear	Linear	Linear	LSTR	Linear	Linear	Linear	LSTR	LSTR	Linear	Linear

	Spain				Finland				France			
	Δe_{t-1}	Δe_{t-2}	Δe_{t-3}	Δe_{t-4}	Δe_{t-1}	Δe_{t-2}	Δe_{t-3}	Δe_{t-4}	Δe_{t-1}	Δe_{t-2}	Δe_{t-3}	bf Δe_{t-4}
H_0	0,028	0,103	0,436	0,206	0,003	0,408	0,981	0,831	0,295	0,439	0,038	0,193
H_{04}	0,036	0,961	0,494	0,492	0,001	0,382	0,986	0,763	0,501	0,703	0,072	0,408
H_{03}	0,115	0,031	0,278	0,439	0,087	0,238	0,663	0,771	0,454	0,205	0,344	0,054
H_{01}	0,390	0,046	0,537	0,065	0,727	0,701	0,796	0,462	0,013	0,071	0,041	0,274
Specification	LSTR	Linear	Linear	Linear	LSTR	Linear	Linear	Linear	Linear	Linear	LSTR	Linear

	Greece				Ireland				Italy			
	Δe_{t-1}	Δe_{t-2}	Δe_{t-3}	Δe_{t-4}	Δe_{t-1}	Δe_{t-2}	Δe_{t-3}	Δe_{t-4}	Δe_{t-1}	Δe_{t-2}	Δe_{t-3}	bf Δe_{t-4}
H_0	0,527	0,392	0,600	0,012	0,000	0,000	0,000	0,018	0,004	0,000	0,004	0,119
H_{04}	0,261	0,444	0,239	0,073	0,020	0,060	0,000	0,041	0,057	0,001	0,0661	0,6194
H_{03}	0,796	0,236	0,922	0,042	0,003	0,000	0,319	0,170	0,013	0,8765	0,036	0,087
H_{01}	0,567	0,621	0,565	0,194	0,056	0,421	0,115	0,133	0,196	0,000	0,061	0,105
Specification	Linear	Linear	Linear	ESTR	ESTR	ESTR	LSTR	LSTR	ESTR	LSTR	ESTR	Linear

	Luxembourg				Netherlands				Portugal			
	Δe_{t-1}	Δe_{t-2}	Δe_{t-3}	Δe_{t-4}	Δe_{t-1}	Δe_{t-2}	Δe_{t-3}	Δe_{t-4}	Δe_{t-1}	Δe_{t-2}	Δe_{t-3}	bf Δe_{t-4}
H_0	0,010	0,062	0,618	0,463	0,177	0,124	0,095	0,037	0,012	0,011	0,926	0,908
H_{04}	0,222	0,417	0,877	0,198	0,336	0,780	0,090	0,129	0,192	0,032	0,900	0,842
H_{03}	0,098	0,121	0,306	0,497	0,198	0,160	0,459	0,384	0,050	0,076	0,790	0,948
H_{01}	0,012	0,056	0,372	0,778	0,271	0,018	0,182	0,028	0,041	0,251	0,544	0,322
Specification	LSTR	Linear	Linear	Linear	Linear	Linear	Linear	LSTR	LSTR	LSTR	Linear	Linear

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. Plots from STR pass-through equation

Figure 1: Estimated logistic transition functions and ERPT as a function of past exchange rate depreciations

Belgium

Greece

Italy

Luxembourg

Portugal
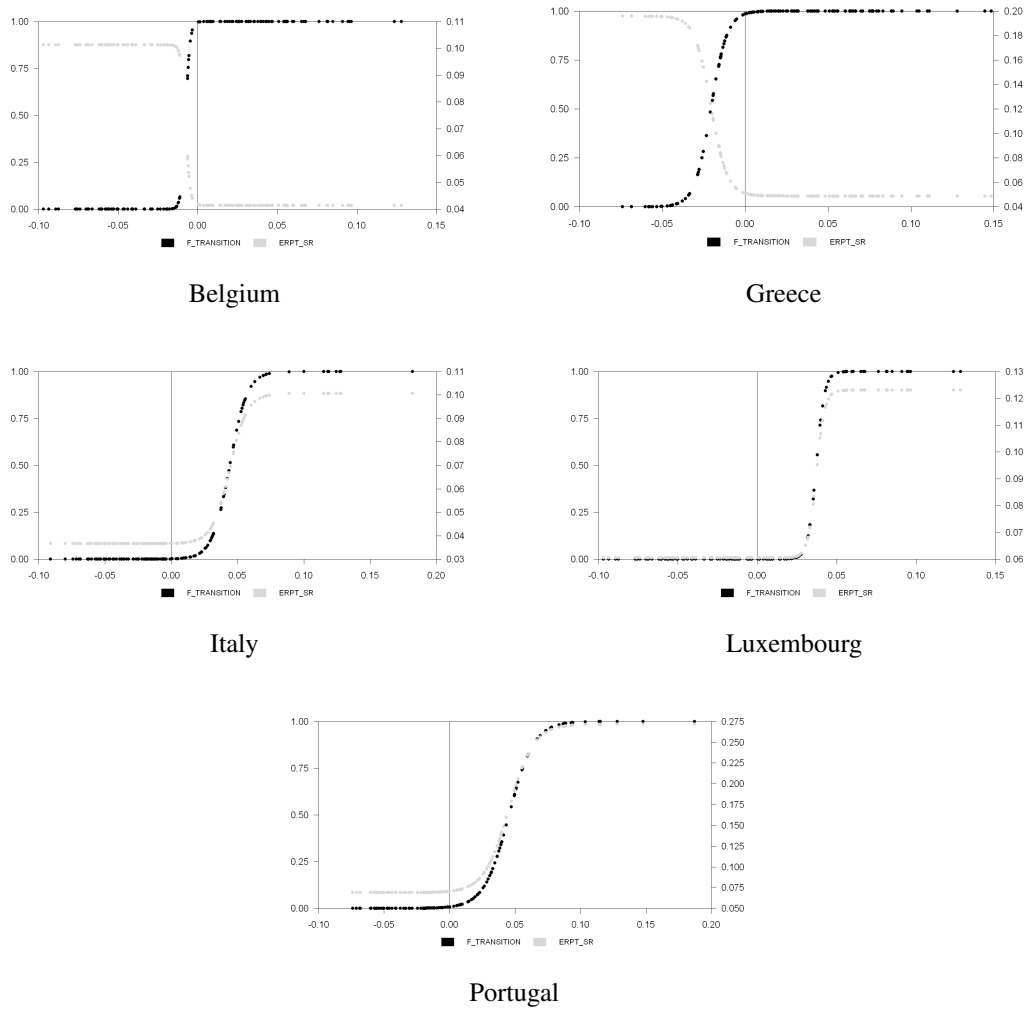
Note: Estimated transition functions and ERPT as function of past exchange rate depreciations. Results are from LSTR model with $s_t = \Delta e_{t-i}$.

Figure 2: Estimated exponential functions and ERPT as a function of past exchange rate depreciations

Belgique   Germany   Spain

Finland   France   Greece

Italy   Luxembourg   Netherlands
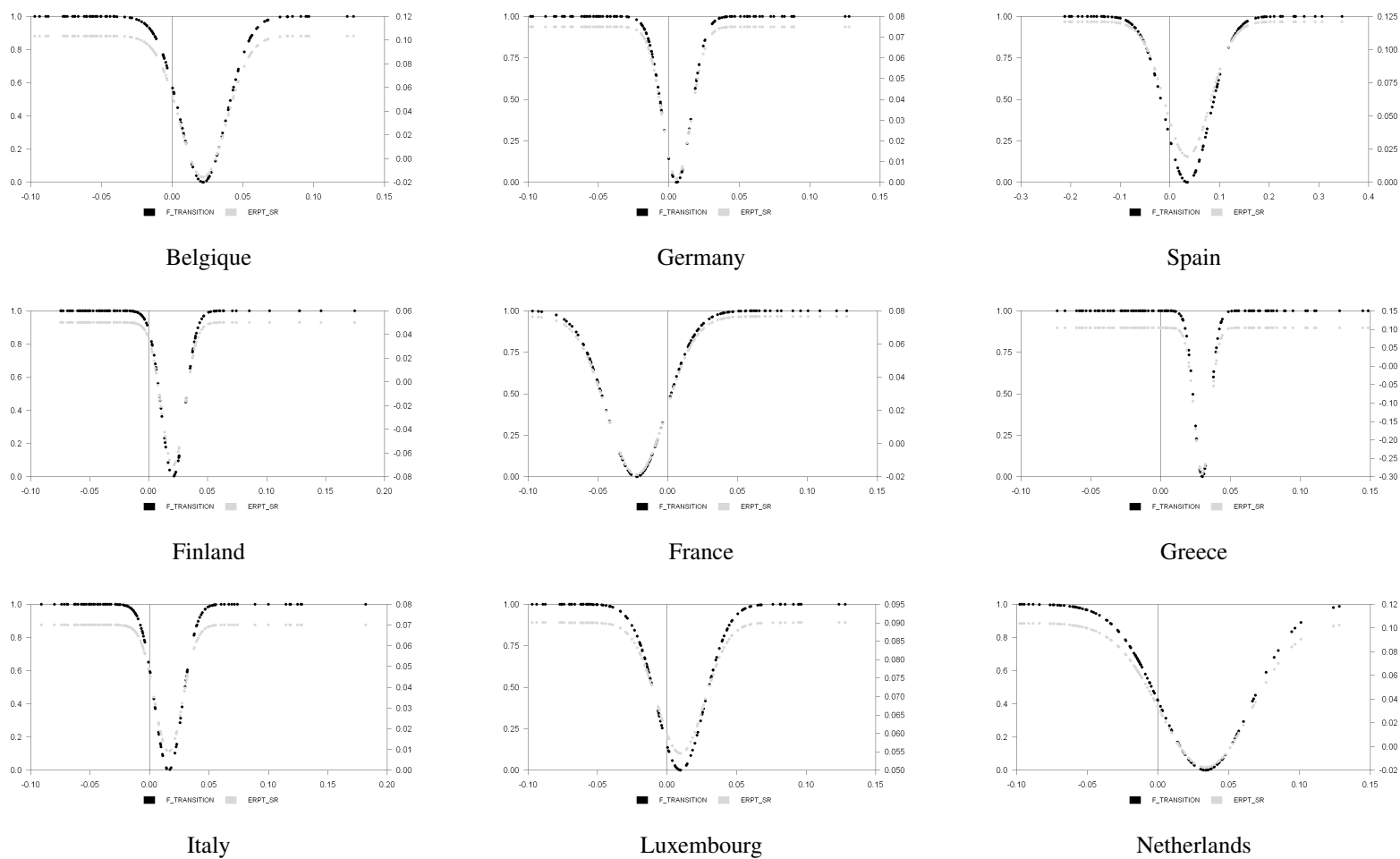
Note: Estimated exponential transition functions and ERPT as a function of past exchange rate depreciations. Results are from ESTR specification with $s_t = \Delta e_{t-i}$.

Figure 3: Time-varying ERPT from ESTR model and past exchange rates depreciations

Belgium

Germany

Spain

Finland

France

Greece

Italy

Luxembourg

Netherlands

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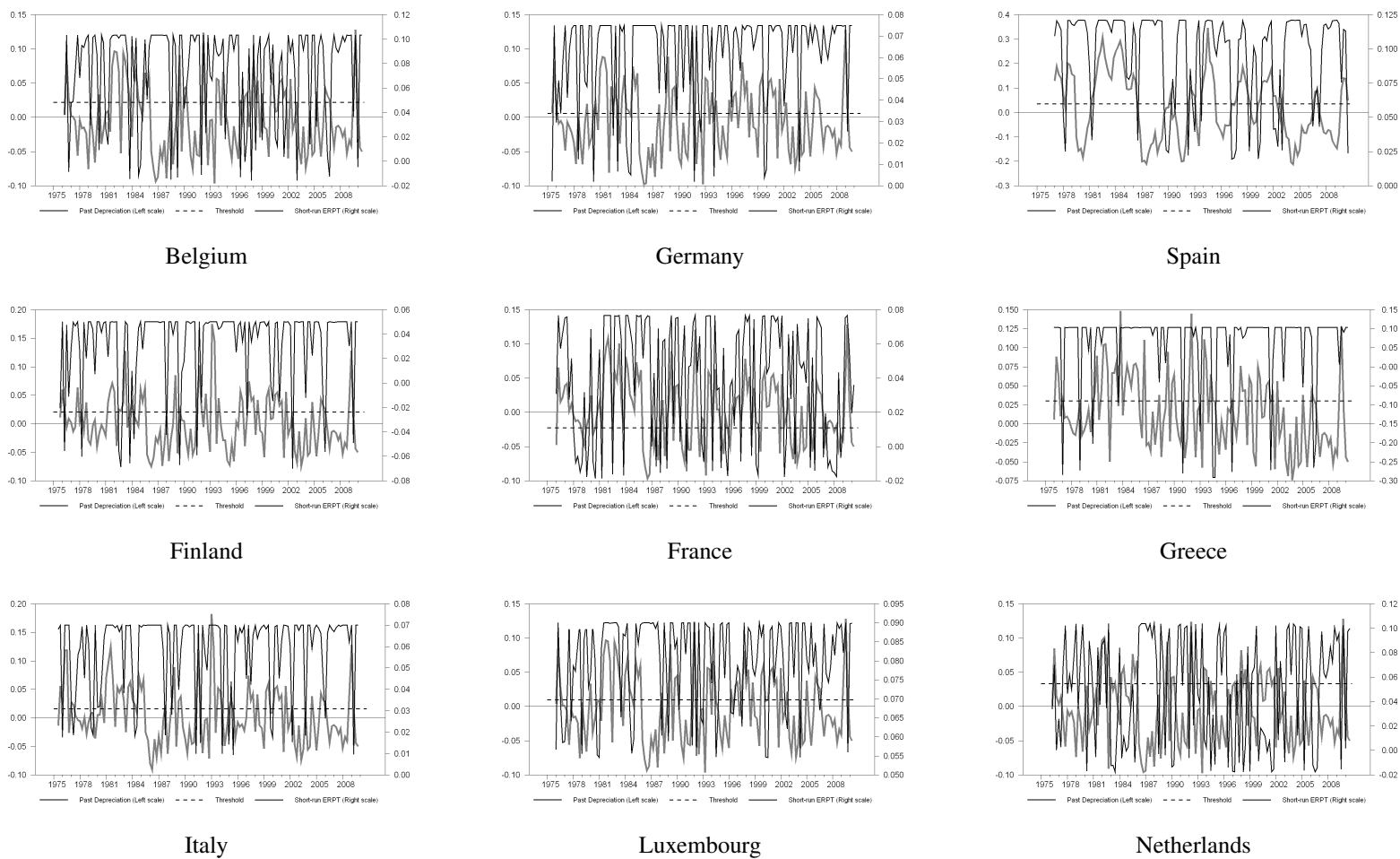
Note: Time-varying ERPT and past exchange rate depreciations during 1975-2010. Results are from ESTR specification with $s_t = \Delta e_{t-i}$.

Appendix C. Full Results from STR pass-through models

Table 4: Estimation results from LSTR model

	Belgique	Grèce	Italie	Luxembourg	Portugal
s_t	Δe_{t-4}	Δe_{t-4}	Δe_{t-2}	Δe_{t-1}	Δe_{t-1}
c	0,004	-0,021	0,044	0,037	0,045
	(0,050)	(0,000)	(0,000)	(0,000)	(0,000)
γ	60,750	9,675	7,513	18,530	5,317
	(0,555)	(0,262)	(0,095)	(0,379)	(0,029)
Linear part: G=0					
Constant	0,005	-0,008	0,000	0,003	0,002
	(0,001)	(0,331)	(0,925)	(0,009)	(0,622)
π_{t-1}		0,545	0,478		
		(0,090)	(0,000)		
π_{t-2}				0,211	
				(0,006)	
π_{t-3}		-0,187	0,089		
		(0,484)	(0,360)		
π_{t-4}	0,445	0,439	0,227	0,330	0,662
	(0,000)	(0,071)	(0,013)	(0,000)	(0,000)
Δe_t	0,101	0,196	0,037	0,060	0,069
	(0,000)	(0,033)	(0,030)	(0,000)	(0,131)
Δe_{t-1}		-0,091	0,052	0,020	
		(0,249)	(0,008)	(0,275)	
Δe_{t-2}	0,032				
	(0,083)				
Δe_{t-3}	0,024				-0,035
	(0,086)				(0,466)
Δe_{t-4}					
Δw_t^*	0,193	0,255	0,075	0,115	0,087
	(0,000)	(0,014)	(0,005)	(0,000)	(0,240)
Δw_{t-1}^*	0,022	-0,114	0,098	0,049	0,013
	(0,196)	(0,314)	(0,005)	(0,057)	(0,816)
Δw_{t-2}^*	0,080				
	(0,002)				
Δw_{t-3}^*					-0,066
					(0,323)
Δw_{t-4}^*					
Δy_t	-0,167			-0,050	
	(0,129)			(0,075)	
Δy_{t-1}		-0,119	0,321		
		(0,339)	(0,000)		
Δy_{t-2}					
Δy_{t-3}		0,146	0,007		0,201
		(0,163)	(0,931)		(0,334)
Δy_{t-4}		0,118			0,026
		(0,139)			(0,904)
Non-linear part: G=1					
Δe_t	-0,060	-0,147	0,064	0,063	0,203
	(0,029)	(0,131)	(0,330)	(0,109)	(0,010)
Δe_{t-1}		0,132	-0,175	-0,051	
		(0,129)	(0,004)	(0,337)	
Δe_{t-2}	-0,005				
	(0,849)				
Δe_{t-3}	-0,009				0,448
	(0,594)				(0,000)
Δe_{t-4}					

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

Table 5: Estimation results from ESTR model

	Belgique	Allemagne	Espagne	Finlande	France	Grèce	Irlande	Italie	Luxembourg	Pays-Bas
s_t	Δe_{t-4}	Δe_{t-1}	Δe_{t-4}	Δe_{t-2}	Δe_{t-3}	Δe_{t-3}	Δe_{t-2}	Δe_{t-1}	Δe_{t-3}	Δe_{t-4}
c	0,022	0,006	0,035	0,021	-0,022	0,030	0,043	0,016	0,010	0,033
	(0,059)	(0,037)	(0,004)	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)	(0,016	0,000
γ	4,381	11,092	4,322	11,347	2,487	33,264	1,274	9,112	4,041	1,128
	(0,000)	(0,062)	(0,110)	(0,004)	(0,064)	(0,053)	(0,025)	(0,105)	(0,057)	0,058
Linear Part: G=0										
Constant	0,004	0,005	-0,005	0,007	-0,002	0,002	0,003	0,003	0,009	-0,003
	(0,188)	(0,181)	(0,306)	(0,166)	(0,332)	(0,956)	(0,504)	(0,532)	(0,001	0,226
π_{t-1}			0,028			-0,495	0,160	0,812		0,391
			(0,896)			(0,591)	(0,267)	(0,015)		0,032
π_{t-2}		0,798					-0,169		0,174	
		(0,007)					(0,301)		(0,478)	
π_{t-3}					0,410	0,049		-0,429		
					(0,007)	(0,919)		(0,274)		
π_{t-4}	0,696		0,748	0,139	0,345	2,068	0,304	0,410	0,290	0,506
	(0,000)		(0,003)	(0,459)	(0,033)	(0,044)	(0,014)	(0,100)	(0,090	0,000
Δe_t	-0,016	0,002	0,019	-0,071	-0,019	-0,291	0,065	0,009	0,055	-0,018
	(0,681)	(0,972)	(0,814)	(0,183)	(0,485)	(0,073)	(0,256)	(0,886)	(0,062)	(0,476)
Δe_{t-1}				-0,046	0,065	0,034	0,023	0,014	-0,006	0,021
				(0,691)	(0,015)	(0,852)	(0,652)	(0,943)	(0,878)	(0,162)
Δe_{t-2}	-0,002		-0,065							
	(0,967)		(0,128)							
Δe_{t-3}	-0,015	-0,099								
	(0,449)	(0,015)								
Δe_{t-4}			-0,019	0,006	-0,038			-0,067		
			(0,611)	(0,864)	(0,027)			(0,125)		
Δw_t^*	-0,064	-0,029	0,059	-0,322	0,045	-0,455	0,062	0,067	0,042	0,017
	(0,479)	(0,779)	(0,731)	(0,029)	(0,159)	(0,006)	(0,594)	(0,426)	(0,393	0,727
Δw_{t-1}^*	-0,041		-0,061	0,012	0,112	0,186	0,176	-0,117	0,016	
	(0,370)		(0,449)	(0,932)	(0,005)	(0,586)	(0,026)	(0,279)	(0,820)	
Δw_{t-2}^*	0,022	-0,129								
	(0,786)	(0,008)								
Δw_{t-3}^*										0,046
										(0,024)
Δw_{t-4}^*		0,009								
		(0,886)								
Δy_t	-0,111		0,012	-0,163					-0,174	0,113
	(0,585)		(0,951)	(0,475)					(0,078)	0,234
Δy_{t-1}						-0,258		0,047		0,195
						(0,412)		(0,817)		(0,003)
Δy_{t-2}		0,165			0,338					-0,015
		(0,062)			(0,024)					(0,826
Δy_{t-3}						0,083	0,037	0,084		
						(0,808)	(0,745)	(0,784)		
Δy_{t-4}		0,100				0,578	0,080			0,044
		(0,246)				(0,175)	(0,567)			(0,416
Non-linear Part: G=1										
Δe_t	0,119	0,073	0,102	0,121	0,095	0,395	-0,076	0,061	0,035	0,122
	(0,006)	(0,200)	(0,253)	(0,040)	(0,008)	(0,018)	(0,294)	(0,370)	(0,329	0,002)
Δe_{t-1}			0,101	-0,059	0,009	0,140	0,022	0,058	-0,002	
			(0,405)	(0,110)	(0,961)	(0,042)	(0,912)	(0,234)	(0,920)	
Δe_{t-2}	0,045		0,054							
	(0,333)		(0,259)							
Δe_{t-3}	0,042	0,112								
	(0,076)	(0,009)								
Δe_{t-4}				0,059	-0,006	0,046		0,057		
				(0,160)	(0,871)	(0,038)		(0,227)		

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