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Federal Reserve Bank of St. Louis, Research Division, P.O. Box 442, St. Louis, MO 63166

Threshold Adjustment in Deviations from the Law of One Price*

Luciana Juvenal
Federal Reserve Bank of St. Louis

Mark P. Taylor
University of Warwick,
Barclays Global Investors
and
Centre for Economic Policy Research

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Abstract

Using self-exciting threshold autoregressive models, we explore the validity of the law of one price (LOOP) for sixteen sectors in nine European countries. We find strong evidence of nonlinear mean reversion in deviations from the LOOP and highlight the importance of modelling the real exchange rate in a nonlinear fashion in an attempt to measure speeds of real exchange rate adjustment. Using the US dollar as a reference currency, the half-lives of sectoral real exchange rates shocks, calculated by Monte Carlo integration, imply much faster adjustment than the 'consensus' half-life estimates of three to five years. The results also imply that transaction costs vary significantly across sectors and countries.

Keywords: Law of One Price, mean reversion, nonlinearities, thresholds.
JEL Classification: F31, F41, C22.

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1 Introduction

Purchasing power parity (PPP) is one of the oldest and most fundamental concepts in economics. Under PPP, aggregate price levels should be the same across countries once expressed in a common currency. A key building block of PPP is the so called Law of one price (LOOP), which states that, at the individual goods level, the prices of homogeneous goods should be the same in spatially separated markets once expressed in a common currency.

An assumption underlying the LOOP is that there is frictionless international goods arbitrage. In practice, it is often observed that prices of similar goods fail to equalize between countries. This evidence contradicts the idea of arbitrage postulated in the LOOP and it is a sign that markets are not completely integrated. One reason why prices of homogeneous commodities may not be the same across different countries is the existence of transaction costs arising from transport costs, tariffs and nontariff barriers. A number of theoretical studies suggest the importance of transaction costs in modelling deviations from the LOOP (e.g. Dumas, 1992; Sercu et al., 1995; O'Connell, 1998). These studies argue that, due to frictions in international trade, deviations from the LOOP may be characterized by nonlinear adjustment. In particular, the persistence of deviations from the LOOP will depend on whether the sectoral exchange rate has crossed a threshold that may reflect transactions costs. Simply put, if the cost of arbitraging is x percent, then there will be no incentive to arbitrage until the deviation from the LOOP has exceeded x percent. In this framework, we can potentially identify two regimes: within the threshold band deviations from the LOOP are indeterminate or borderline nonstationary and outside the band they are mean reverting towards the band because of the effects of arbitrage. The first regime occurs when deviations from the LOOP are smaller than transaction costs and consequently are not worth arbitraging. In this case the real exchange rate will not exhibit any tendency to move back to equilibrium and the LOOP does not hold. In the second regime, deviations from the LOOP are higher than the transaction costs, arbitrage is profitable and the process becomes mean reverting.

Based on these theoretical contributions, a number of empirical studies investigate the nonlinear nature of deviations from the LOOP (Obstfeld and Taylor, 1997; Sarno, Taylor and Chowdhury, 2004) in terms of a threshold autoregressive (TAR) model (Tong, 1990). The TAR model allows for the presence of a 'band of inaction' within which no trade takes place. Hence, inside the band deviations from the LOOP exhibit unit root behavior. Outside the band the process can become mean reverting.

These empirical studies provide evidence of the presence of nonlinearities in deviations from the LOOP. However, they are sometimes criticized on three counts. The first is that they are based on relatively few commodities or currencies. The second is related to the temporal aggregation problem that arises when using annual or quarterly data, such that the degree of upward bias in the estimated persistence of the real exchange rate rises with the degree of temporal aggregation in the data (see e.g. Taylor, 2001).[1] The third is associated with calculation of the speed of mean reversion, which is usually considered to be given by the autoregressive process outside the band and ignores the adjustment process of the model as a whole.

In order to overcome the first two limitations, in our paper we use a highly disaggregated monthly database previously analyzed by Imbs et al. (2003, 2005). The main difference between the work of Imbs et al. (2003) and our paper is that the former focuses on the determinants of international trade segmentation. In contrast, our goal is to examine the general validity of the LOOP. In order to do this, we show that the low power of standard unit root tests motivates the study of deviations from the LOOP in a nonlinear fashion. In particular, we test the validity of modelling deviations from the LOOP allowing for nonlinearities and estimate a TAR model for each sectoral real exchange rate.

More precisely, in our baseline specification we investigate the presence of threshold-type nonlinearities in deviations from the LOOP using real dollar sectoral exchange rates *vis-à-vis* nine major European currencies for sixteen sectors over the period 1981-1998. A total of one hundred and 43 sectoral real exchange rates are analyzed[2]. Nonlinearities are modelled using a self-exciting threshold autoregressive (SETAR) model.

Our results suggest that the SETAR model characterizes well deviations from the LOOP for a broad range of currencies and disaggregated goods sectors. We also find reasonable estimates of transaction costs and convergence speeds which are in line with the theoretical literature on transaction costs in international goods arbitrage. Overall, there is wide variation in the results across countries and across sectors. This is partly due to the different nature of the sectors analyzed. In addition, there is also a country effect: some countries exhibit relatively low thresholds for a given sector.

There is a certain consensus in the literature that aggregate real exchange rates may converge to a long-run equilibrium but that the speed at which this occurs seems to be very slow (Lothian and Taylor, 1996, 1997; Taylor, 1995, 2003; Rogoff, 1996).[3] A standard measure of the speed of mean reversion is the half-life, which is the time taken for half of the effects of a real exchange rate shock to die out. Rogoff (1996) points out that the 'consensus estimates' of the half-lives of shocks to the real exchange rate are typically in the range of three to five years. Since the short-run

[1] In a related study, Paya and Peel (2006) generate artificial data at high frequency from an ESTAR model and study the effects of temporal aggregation on estimates of the ESTAR model and on nonlinearity tests. According to their findings, nonlinearities are generally preserved in the temporally aggregated data. In contrast to Taylor (2001), their results show that the half-lives decline the more aggregated the data. The different conclusions in these studies could be due to the consideration of different data generating processes. Whereas Taylor (2001) estimates linear models on the temporally aggregated data and shows that the half-lives can be downward biased, Paya and Peel (2006) assume that the true data generating process follows an ESTAR model.

[2] Due to missing data we do not have one hundred and 44 exchange rate time series.

[3] This literature has tended to concentrate on necessary conditions for long-run absolute purchasing power parity to hold. An exception is the recent paper by Coakley, Flood, Fuertes and Taylor (2005), who test for long-run relative PPP.

volatility in real exchange rates suggest that real exchange rate shocks typically arise mainly due to monetary or financial shocks, these shocks can have real effects on the macroeconomy and on macroeconomic variables such as the real exchange only because of the presence of nominal rigidities. However, half-lives from three to five years seem much too large to be explained by nominal rigidities. Hence, Rogoff (1996) terms this result the 'Purchasing Power Parity Puzzle'.[4]

The method of calculation of the half-life of adjustment turns out to be of the utmost importance to examine the PPP puzzle. Interestingly, previous studies of deviations from the LOOP using a SETAR model calculate the half-life based on the speed of convergence in the outer regime of the model. In other words, they compute the convergence relative to the threshold band as if it were a linear model. While some studies emphasized that it was not clear whether the method of computation of half-lives for linear models was applicable to nonlinear models (e.g. Lo and Zivot, 2001), it became a convention to use this measure. In order to shed some light on the mean-reverting properties of the sectoral real exchange rates we consider the regime switching that takes place within and outside the band in the SETAR model. In particular, we compute the half-lives using the procedure for estimating generalized impulse response functions described in Koop, Pesaran and Potter (1996), thus distinguishing the present paper from most of the previous empirical literature on this topic.[5]

Our results show that the speed of mean reversion depends on the size of the shocks. Larger shocks mean-revert much faster than smaller ones. In a minority of cases, our nonlinear model yields half-lives consistent with the 'consensus' estimates of three to five years for small shocks. For larger shocks, however, all half-lives much smaller than three years are reported.

Overall, our results confirm the importance of deviating from a linear specification when modelling deviations from the LOOP (Taylor, Peel and Sarno, 2001; Sarno, Taylor and Chowdhury, 2004), shed some light to the problem of temporal aggregation analyzed in Taylor (2001) and also highlight the importance of calculating half-lives taking into account the SETAR model as a whole rather than just the outer regimes.

The remainder of the paper is organized as follows. Section 2 presents the motivation for modelling the exchange rate in a nonlinear fashion. Section 3 outlines

[4]Since Rogoff's (1996) paper, there has been a great deal of research effort directed towards the study of highly persistent series in the context of linear models. One strand of the literature has focused on the development of new econometric techniques to construct half-lives for near unit root processes. Rossi (2005), for example, summarizes the "state of the art" in the topic and proposes a new methodology to calculate the half-life and confidence interval of a general highly persistent autoregressive process. Rossi shows that the lower bounds of the confidence interval for the real exchange rate are 4 to 8 quarters (there is no PPP puzzle) but that the upper bounds are infinite (inconsistent with PPP).

[5]Taylor, Peel and Sarno (2001) also compute the half-lives using generalized impulse responses. They do this for a different model, an ESTAR model, and for a different purpose, the study of aggregate real exchange rates. The LOOP papers mentioned above compute the half-lives in the conventional way.

the Self-Exciting Threshold Autoregressive (SETAR) model to be estimated and the econometric techniques we employ. Section 4 presents results of tests for nonlinearity. Section 5 describes the data to be used. Preliminary unit root tests results are discussed in Section 6 and Section 7 contains our estimation results and diagnostic tests. Finally, we make some concluding comments in Section 8.

2 Nonlinear Exchange Rate Dynamics: Empirical Evidence and Theoretical Framework

The LOOP states that once prices are converted to a common currency, homogenous goods should sell for the same price in different countries. Using the US as the reference country, let us define deviations from the LOOP for country i in sector j at time t as

$$q_{jt}^{i} = s_{t}^{i} + p_{jt}^{i} - p_{jt}^{US} \tag{1}$$

where s_t^i is the logarithm of the nominal exchange rate between country i's currency and the US dollar (defined as the number of dollars per unit of foreign currency)[6], p_{jt}^{i} is the logarithm of the price of good j in country i at time t and p_{jt}^{US} is the logarithm of the price of good j in the US at time t.

The idea behind the LOOP is that if prices of identical goods differ in two countries there is a profitable arbitrage opportunity: the good can be bought in the country in which it costs less and sold at a higher price in the other country.

The failure of the LOOP has been documented in early studies (Isard, 1977; Richardson, 1978 and Giovannini, 1988). Within this strand of the literature, the evidence also suggests that deviations from the LOOP are significant, very volatile and highly correlated with exchange rate movements.

The reasons why prices of similar goods may vary across locations has been widely analyzed in the international trade literature. One approach, which is the one we adopt in the present study, follows Heckscher's (1916) idea that prices of homogeneous commodities may not be the same across different countries due to the existence of transaction costs in international arbitrage. If two homogeneous goods (once expressed in a common currency) are sold at different prices in two locations, the LOOP does not hold, and it will not be worth arbitraging and consequently lead to a price equalization unless the anticipated benefit exceeds the transport costs between the two locations.

[6] As a consequence, an increase in the nominal exchange rate indicates an appreciation of country i's currency (depreciation of the dollar). Hence, a rise in q_{jt}^{i} indicates a real appreciation for country i (real depreciation for the US).

These frictions to trade can imply the presence of nonlinearities in international goods arbitrage. This idea began to be formalized in the theoretical literature in the 1980s and early 1990s (Williams and Wright, 1991; Dumas, 1992; Sercu et al., 1995). In these studies the lack of arbitrage arises from transaction costs such as transport costs. In most cases transport costs are modeled as a waste of resources—if a unit of good is shipped from one location to another, a fraction melts on its way, so that only a proportion of it arrives. These transaction costs create a 'band of inaction' for the real exchange rate within which the marginal cost of arbitrage exceeds the marginal benefit. Hence, within this band there is a no-trade zone and prices in two locations are disconnected.

It is clear that transport costs are not the only trade friction. In fact, the role of tariffs and nontariff barriers as a potential driver of price differentials between countries has also been explored. Tariffs clearly create a wedge between domestic and foreign prices. Although they have been falling in the last decades, they are still important for some commodities. Nontariff barriers may be another source of friction in international goods arbitrage but the empirical evidence offers mixed findings on its relevance to explain deviations from the LOOP. Knetter (1994), for example, argues that nontariff barriers are important empirically to explain deviations from PPP. In contrast, Obstfeld and Taylor (1997) do not find nontariff barriers to be a significant explanator of deviations from the LOOP.

Another factor that may lead to a failure of goods market arbitrage is the presence of nontraded components in goods that appear to be highly tradable. This becomes more relevant when consumer price indices are considered. Labour costs and taxes, for example, are likely to differ across different locations and they may affect final local goods prices.

Overall, all of these frictions can create a wedge between prices of different countries and the estimated transaction costs band may be wider than the one implied by transport costs[7]. This point was considered in Dumas (1992). He studies a two-country general equilibrium model in the framework of a homogenous investment-consumption good. Dumas finds that in the presence of sunk costs of arbitrage and random productivity shocks trade takes place only when there are sufficiently large arbitrage opportunities. When this happens the real exchange rate displays mean-reverting properties.

O'Conell and Wei (2002) extend the analysis using a broader interpretation of market frictions operating at the level of technology and preferences. Their model also allows for fixed and proportional market frictions. When both types of costs of trade are present they find that two 'bands' for deviations from the LOOP are

[7] As a reference point, an estimate of international transportation costs can be obtained by comparing the 'free on board' (FOB) value of world exports, which exclude shipping costs and insurance, with the 'cost, insurance and freight' (CIF) value of world imports, which include shipping and insurance costs. Estimates by the International Monetary Fund, for example, suggest that the difference is around 10 per cent.

generated. The idea is that arbitrage will be strong when it is profitable enough to outweigh the initial fixed cost. In the presence of proportional arbitrage costs, the quantity of adjustments are very small, sufficient to prevent price deviations from growing but insufficient to return the LOOP deviations to equilibrium.

Based on these theoretical studies, it is possible to estimate a model in which the real exchange rate has no tendency to adjust unless it has crossed a threshold equal to the transaction costs. This implies that within the threshold band changes in the real exchange rate are random and outside the band the process can become mean reverting when arbitrage takes place. This kind of model is the TAR (Tong, 1990) and it applies to individual commodities. Recent studies that analyze deviations from the LOOP in a threshold-type framework include Obstfeld and Taylor (1997), Taylor (2001), Imbs et al. (2003) and Sarno, Taylor and Chowdhury (2004).

Obstfeld and Taylor (1997) use aggregated and disaggregated data on clothing, food and fuel for 32 city and country locations employing monthly data from 1980 to 1995. They estimate the half-lives of deviations from the LOOP as well as the thresholds. Their location average estimated thresholds are between 7% and 10%. They also find a considerable variation in their estimates across sectors and countries.

Taylor (2001) investigates the impact of temporal aggregation in the data when testing for the LOOP. Using a Monte Carlo experiment with an artificial nonlinear data generating process he finds that the upward bias in the estimated half-lives rises with the degree of temporal aggregation. He also shows that the estimated half-lives have a considerable bias when the model is assumed to be linear when in fact there is a nonlinear adjustment.

The main purpose of Imbs et al. (2003) is to study the determinants of barriers to arbitrage. They do so by estimating TAR models for 171 sectoral real exchange rates. Although they do not directly report the results of their TAR estimation (because that is not the main point of their paper), they claim strong evidence of mean reversion.

Sarno, Taylor and Chowdhury (2004) use annual data on prices (interpolated into quarterly) for nine sectors and quarterly data on five exchange rates *vis-à-vis* the US dollar (UK pound, French franc, German mark, Italian lira and Japanese yen) from 1974 to 1993. Using a SETAR model, they find strong evidence of nonlinear mean reversion with half-lives and threshold estimates varying considerably both across countries and across sectors.

In summary, all of these studies find supportive evidence of the LOOP when allowing for nonlinear exchange rate adjustment. Mean reversion takes place when LOOP deviations are large enough to allow for profitable arbitrage opportunities.

All the previous studies use a TAR model to analyze the validity of the LOOP. As noted by Taylor, Peel and Sarno (2001) and Taylor and Taylor (2004), this model is very appealing in the context of individual goods but it is clear that for the aggregate real exchange rate it may be inappropriate. Transaction costs are likely to differ across sectors and consequently the speed of arbitrage may differ across goods. One could think that the aggregate real exchange rate is made up of goods prices with different implied thresholds. Some of these thresholds may be small and others will be larger. This means that as the real exchange rate moves away from equilibrium, more thresholds are crossed and thus the arbitrage forces become more powerful. Hence, one could expect that adjustment of the aggregate real exchange rate would be smooth rather than discrete and that the speed of adjustment would increase with the size of the deviation from equilibrium.[8]

The approach from the present paper differs from previous studies for at least three reasons. First, in contrast to studies that use data at the quarterly frequency, we intend to overcome the temporal aggregation bias described in Taylor (2001) using a highly disaggregated monthly database. Second, we estimate a SETAR model without imposing the lag length. In particular, we choose the optimal lag on the basis of an information criterion. Finally, we compute the half-lives of deviations from the LOOP using generalized impulse response functions.

3 Econometric Method: Model and Estimation

The theoretical models described in the previous section motivate the study of deviations from the LOOP using a nonlinear model. As explained before, the presence of transaction costs may generate a 'band of inaction' (or thresholds) within which the costs of arbitrage exceed its benefits. Hence, inside the band, there is a no-trade zone where deviations from the LOOP are persistent. Once above or below this band, arbitrage takes place and deviations from the LOOP could become mean reverting.[9] Empirically, this pattern is described by a threshold autoregressive (TAR) model, which was originally popularized by Balke and Fomby (1997) in the context of testing for PPP and the LOOP.

Denote the real exchange rate (deviations from the LOOP) for a sector j in country i at time t as q^i_{jt}. A simple three-regime TAR model (TAR) may be written as

[8] This can be modeled using a smooth transition autoregressive (STAR) specification. See e.g. Taylor, Peel and Sarno (2001), Kilian and Taylor (2003) and Lothian and Taylor (2008).

[9] The discrete switching implied by the TAR model seems appealing when considering the effects of arbitrage on disaggregated goods prices. In contrast, when the aggregate real exchange rate is considered, smooth adjustment may become more appropriate (see Taylor, Peel and Sarno, 2001) and a Smooth Transition Autoregressive Model (STAR) can be used. It could be argued that the dynamics of the aggregate real exchange rate occurs as a result of the combination of adjustments of different disaggregated sectors with non identical transaction costs. In other words, the aggregate real exchange rate is measured using price indices consisting of sectoral goods prices each with a different threshold. The STAR model can be understood as a being composed by a series of TARs with different implied transaction costs. Thus, the more the real exchange rate moves away from equilibrium, the more thresholds are crossed and consequently the faster the real exchange rate will mean revert.

$$\Delta q_{jt}^{i} = \gamma q_{jt-1}^{i} + \sum_{p=1}^{P-1} \alpha_p \Delta q_{jt-p}^{i} + \varepsilon_{jt}^{i} \text{ if } \left| q_{jt-d}^{i} \right| \leqslant \kappa \tag{2}$$

$$\Delta q_{jt}^{i} = (\beta_1 - 1)\left(q_{jt-1}^{i} - \kappa\right) + \sum_{p=2}^{P} \beta_p (q_{jt-p}^{i} - \kappa) + \varepsilon_{jt}^{i} \quad \text{if } q_{jt-d}^{i} > \kappa \tag{3}$$

$$\Delta q_{jt}^{i} = (\beta_1 - 1)\left(q_{jt-1}^{i} + \kappa\right) + \sum_{p=2}^{P} \beta_p (q_{jt-p}^{i} + \kappa) + \varepsilon_{jt}^{i} \quad \text{if } q_{jt-d}^{i} < -\kappa \tag{4}$$

$$\epsilon_{jt}^{i} \sim N(0, \sigma^2) \tag{5}$$

where Δ is the difference operator, κ is the threshold parameter, q_{jt-d}^{i} is the threshold variable for sector i and country j, p is the autoregressive order selected via the Akaike Criterion and d denotes the delay parameter—an integer chosen from the set $\Psi \in \left[1, \overline{d}\right]$. The delay parameter captures the idea that it takes time for economic agents to react to deviations from the LOOP. The error term is assumed to be independently and identically distributed (iid) Gaussian.

This type of model in which the threshold variable is assumed to be the lagged dependent variable is called Self-Exciting TAR (SETAR). Hence, the model outlined is a SETAR $(p, 2, d)$, where 2 refers to the fact that there are two thresholds. Following Obstfeld and Taylor (1997) we assume that the thresholds are symmetric (transaction costs are equal if prices are higher in one location or in another) and that arbitrage forces operate in the same way if deviations from the LOOP occur above or below the threshold band.

In order to account for the fact that deviations from the LOOP would be persistent within the threshold band, restrictions on the parameters can be adopted. In this case, we make the simplifying assumption that $\gamma = 0$. This implies that within the band, $\left| q_{jt-d}^{i} \right| \leqslant \kappa$, deviations from the LOOP follow a unit root process. Given that arbitrage is not profitable, in the inner regime q_{jt}^{i} shows no tendency to move back towards equilibrium.

In contrast, in the outer regime, $\left| q_{jt-d}^{i} \right| > \kappa$, deviations from the LOOP switch to a different autoregressive process that is stationary and hence has a tendency to revert to equilibrium if $\sum_{p=1}^{P} \beta_p < 1$. Note that this specification assumes that reversion is towards the *edge* of the band.

We can rewrite the model in (2)-(5) together with the restriction $\gamma = 0$ using the indicator functions $1\left(q_{jt-d}^{i} > \kappa\right)$, $1\left(q_{jt-d}^{i} < -\kappa\right)$ and $1\left(\left| q_{jt-d}^{i} \right| \leqslant \kappa\right)$, each of which takes value equal to one if the inequality is satisfied and zero otherwise

$$\Delta q_{jt}^{i} = \left[(\beta_1 - 1)\left(q_{jt-1}^{i} - \kappa\right) + \sum_{p=2}^{P} \beta_p (q_{jt-p}^{i} - \kappa) \right] 1\left(q_{jt-d}^{i} > \kappa\right) + \left[\sum_{p=1}^{P-1} \alpha_p \Delta q_{jt-p}^{i} \right] 1\left(\left|q_{jt-d}^{i}\right| \leqslant \kappa\right) + \left[(\beta_1 - 1)\left(q_{jt-1}^{i} + \kappa\right) + \sum_{p=2}^{P} \beta_p (q_{jt-p}^{i} + \kappa) \right] 1\left(q_{jt-d}^{i} < -\kappa\right) + \epsilon_{jt}^{i} \tag{6}$$

For purposes of exposition, re-write equation (6) as

$$\Delta q_{jt}^{i} = B_{jt}^{i}(\kappa, d)'\Gamma + \epsilon_{jt}^{i} \tag{7}$$

where $B_{jt}^{i}(\kappa, d)'$ is a (1×3) row vector that describes the behavior of Δq_{jt}^{i} in the outer and inner regimes and Γ is a (3×1) vector containing the autoregressive parameters to be estimated. In particular,

$$B_{jt}^{i}(\kappa, d)' = \left[\begin{array}{ccc} X'1\left(q_{jt-d}^{i} > \kappa\right) & Y'1\left(\left|q_{jt-d}^{i}\right| \leqslant \kappa\right) & Z'1\left(q_{jt-d}^{i} < -\kappa\right) \end{array} \right] \tag{8}$$

where,

$X' = \left[\begin{array}{cccc} (q_{jt-1}^{i} - \kappa) & (q_{jt-2}^{i} - \kappa) & ... & (q_{jt-p}^{i} - \kappa) \end{array} \right]$,

$Y' = \left[\begin{array}{cccc} \Delta q_{jt-1}^{i} & \Delta q_{jt-2}^{i} & ... & \Delta q_{jt-p}^{i} \end{array} \right]$ and

$Z' = \left[\begin{array}{cccc} (q_{jt-1}^{i} + \kappa) & (q_{jt-2}^{i} + \kappa) & ... & (q_{jt-p}^{i} + \kappa) \end{array} \right]$.

Also,

$\Gamma' = \left[\begin{array}{ccc} \beta & \alpha & \beta \end{array} \right]$

where,

$\beta' = \left[\begin{array}{ccccc} \beta_1 - 1 & \beta_2 & \beta_3 & ... & \beta_p \end{array} \right]$ and $\alpha' = \left[\begin{array}{ccccc} \alpha_1 & \alpha_2 & ... & \alpha_{p-1} & 0 \end{array} \right]$.

The parameters of interest are Γ, κ and d. Equation (8) is a regression equation nonlinear in parameters and can be consistently estimated under weak regularity conditions using nonlinear using least squares. For a given value of κ and d the least squares estimate of Γ is

$$\widehat{\Gamma}(\kappa, d) = \left(\sum_{t=1}^{T} B_{jt}^{i}(\kappa, d) B_{jt}^{i}(\kappa, d)' \right)^{-1} \left(\sum_{t=1}^{T} B_{jt}^{i}(\kappa, d) \Delta q_{jt}^{i} \right) \tag{9}$$

with residuals $\widehat{\epsilon}_{jt}^{i}(\kappa, d) = \Delta q_{jt}^{i} - B_{jt}^{i}(\rho, d)'\widehat{\Gamma}(\kappa, d)$, and residual variance

$$\widehat{\sigma}^2(\kappa, d) = \frac{1}{T}\sum_{t=1}^{T}\widehat{\epsilon}^i_{jt}(\kappa, d)^2 \tag{10}$$

Since the values of κ and d are not given, they should be estimated together with the autoregressive parameter. Hansen (1997) suggests a methodology to identify the model in (7) that consists on the simultaneous estimation of κ, and d via a grid search. The model is estimated by sequential least squares for integer values of d from 1 to $\overline{d} \leq p$. The values of κ and d that minimize the sum of squared residuals are chosen. This can be written as

$$\left(\widehat{\kappa}, \widehat{d}\right) = \underset{\kappa\in\Theta,\ d\in\Psi}{\arg\min}\,\widehat{\sigma}^2\left(\kappa, d\right) \tag{11}$$

where $\Theta = [\underline{\kappa}, \overline{\kappa}]$.

The least squares estimator of Γ is $\widehat{\Gamma} = \widehat{\Gamma}\left(\widehat{\kappa}, \widehat{d}\right)$ with residuals $\widehat{\epsilon}^i_{jt}\left(\widehat{\kappa}, \widehat{d}\right) = \Delta q^i_{jt} - B^i_{jt}(\widehat{\kappa}, \widehat{d})'\widehat{\Gamma}\left(\widehat{\kappa}, \widehat{d}\right)$ and residual variance $\widehat{\sigma}^2\left(\widehat{\kappa}, \widehat{d}\right) = \frac{1}{T}\sum_{t=1}^{T}\widehat{\epsilon}^i_{jt}\left(\widehat{\kappa}, \widehat{d}\right)^2$.

4 Testing for Nonlinearity

Before analyzing the results from the estimation of the SETAR model, it is important to test whether the nonlinear specification is superior to a linear model.

As noted by Hansen (1997), testing this hypothesis is not that straightforward. A statistical problem is present because conventional test statistics to test the null hypothesis of a linear autoregressive model against the alternative of a SETAR model have nonstandard asymptotic distributions due to the presence of nuisance parameters. These parameters are not identified under the null hypothesis of linearity. It can be seen that in the model in (6) the nuisance parameters are the threshold κ and the delay d.

In order to overcome the inference problems derived from the nonstandard asymptotic distributions of the tests, Hansen (1997) developed a bootstrap method to replicate the asymptotic distribution of the classic F-statistic. This method requires the estimation of both the linear model under the null hypothesis and the TAR model under the alternative hypothesis.

If errors are *iid* the null hypothesis of a linear model against the alternative can be tested using the statistic

$$F_T(\kappa, d) = T\left(\frac{\widetilde{\sigma}^2 - \widehat{\sigma}^2(\kappa, d)}{\widehat{\sigma}^2(\kappa, d)}\right), \tag{12}$$

where F_T is the pointwise F-statistic when κ and d are known, T is the sample size, and $\widetilde{\sigma}^2$ and $\widehat{\sigma}^2(\kappa, d)$ are the estimates of the residual variance corresponding to the linear AR(p) and SETAR $(p, 2, d)$ models, respectively.

Since κ and d are not identified under the null hypothesis, the distribution of $F_T(\kappa, d)$ is not central χ^2. Hansen (1997) shows that the asymptotic distribution of $F_T(\kappa, d)$ may be approximated using the following bootstrap procedure. Let $y_{jt}^{i*}, t = 1, ..., T$ be *iid* $N(0,1)$ random draws, and set $q_{jt}^{i*} = y_{jt}^{i*}$. Using the observations q_{jt-1}^{i}, $q_{jt-2}^{i}, ..., q_{jt-p}^{i}$ for $t = 1, ..., T$, regress y_{jt}^{i*} on q_{jt-1}^{i}, $q_{jt-2}^{i}, ..., q_{jt-p}^{i}$ and estimate the restricted and unrestricted models and obtain the residual variances $\widetilde{\sigma}^{*2}$ and $\widehat{\sigma}^{*2}(\kappa, d)$, respectively. With these residual variances, it is possible to calculate the following F-statistic:

$$F_T^*(\kappa, d) = T\left(\frac{\widetilde{\sigma}^{*2} - \widehat{\sigma}^{*2}(\kappa, d)}{\widehat{\sigma}^{*2}(\kappa, d)}\right). \qquad (13)$$

The bootstrap approximation to the asymptotic p-value of the test is calculated by counting the number of bootstrap samples for which $F_T^*(\kappa, d)$ exceeds the observed $F_T(\kappa, d)$.

5 Data

Data on disaggregated price levels for European countries was obtained from Eurostat[10] and for the US was obtained from Eurostat and the US Bureau of Labour Statistics. The data set contains monthly observations on two-digit consumer prices (CPI) for sixteen goods categories. The period analyzed is 1981:01 to 1998:12. Our sample period ends in 1998 due to the introduction of the euro in January 1999. The countries covered are Belgium, Denmark, Germany, France, Italy, Netherlands, Portugal, Spain, UK and the US as a reference country. The sectors analyzed are: bread and cereals (*bread*), meat (*meat*), dairy products (*dairy*), fruits (*fruits*), tobacco (*tobac*), alcoholic and non alcoholic drinks (*alco*), clothing (*cloth*), footwear (*foot*), fuels and energy (*fuel*), furniture (*furniture*), domestic appliances (*dom*), vehicles (*vehicles*), communication (*comm*), sound and photographic equipment (*sound*), books (*books*) and hotels (*hotels*).

The monthly series on nominal dollar exchange rates are taken from the *International Financial Statistics* database of the International Monetary Fund.

Dollar sectoral real exchange rates q_{jt}^{i} in logarithmic form are calculated *vis-à-vis* the nine European currencies of the countries mentioned before in the way defined in equation (1). Each series is demeaned in order to account for the existence of different long run equilibrium levels of the sectoral real exchange rate.

[10]Part of this data was used by Imbs *et.al.* (2003 and 2005).

6 Unit Root Tests

The existence of a unit root in the sectoral real exchange rate is economically meaningful because it conveys that it has no tendency to adjust to its long-run equilibrium. Consequently, prices in different locations would have no tendency to equalize and the LOOP would not hold.

We tested the hypothesis that deviations from the LOOP are nonstationary by applying a battery of standard linear unit root tests. Table 1.A presents the Dickey-Fuller test (the other tests are not reported here but available from the authors upon request): for each of the sectoral exchange rates the null hypothesis of a unit root was generally not rejected at conventional significance levels.

Given the high persistence of the real exchange rate, unit root tests tend to do a poor job in most cases. Table 2 shows a simulation of the power of the Dickey Fuller test for p=0.01 and p=0.05 significance levels. The power of the test represents the number of times the test rejects the unit root null hypothesis given that the process is stationary. From these results it follows that the test does not perform well for highly persistent autoregressive processes (i.e. ρ higher than 0.90). Given that the power is generally very low, the test is weak. This highlights the importance of accounting for nonlinearities when modelling real exchange rate dynamics. A failure to do this may lead us to conclude that the exchange rate follows a nonstationary process when in fact may be nonlinearly mean reverting.

Taylor (2001) points out that the problem of low power of conventional unit root tests is exacerbated when the true process is nonlinear. Assuming the real exchange rate follows an AR(1) process, he shows that when the exchange rate displays nonlinear adjustment, the estimate of the autoregressive parameter would be biased upwards (i.e. towards 1). This will bias the 't-statistic' of the Dickey-Fuller test downwards in absolute value, making it more difficult to reject the unit root null hypothesis.

In a related study, Psaradakis (2001) analyses the performance of unit root tests in the case of an autoregressive process subject to multiple level shifts. In contrast to Taylor (2001), the shifts are modelled as a Markov chain. The study shows that when the data generating mechanism is stationary but the transition probabilities in the Markov process are highly persistent (as is the case for financial data) the unit root tests are very weak.

By and large, the general problem with standard unit root tests is that they assume a symmetric adjustment process. It is clear that if the true model is nonlinear, adjustment would be asymmetric. In order to account for this we applied the Enders and Granger (1998) threshold unit root test.[11] The procedure developed by Enders and Granger (1998) can be understood as a generalization of the Dickey-Fuller test and can be used to test the null hypothesis of a unit root against an alternative of stationarity with threshold adjustment. Its main advantage is that in a wide range of cases it is more powerful than the Dickey-Fuller test. The test performs particularly

[11] The authors are grateful to an anonymous referee for suggesting the discussion of this test.

better the more asymmetric is the process.

Table 1.B shows the results of the Enders and Granger test applied to our data. This test rejects the unit root null at the 5% level in around 30% of the series in contrast to a 15% rejection when employing the linear Dickey-Fuller test. A simulation of the power of the Enders and Granger test is presented in Table 2 for different values of the autoregressive parameter and κ=0.1. The test performs slightly better than the Dickey-Fuller test but the power nevertheless remains low for highly persistent series.

This analysis reinforces the argument of Taylor (2001) that it seems reasonable to replace the unit root null hypothesis with a stationary null when testing the validity of the LOOP given that the deviations from the LOOP may be stationary but have a local unit root in the inner regime.

7 Empirical Results

7.1 Estimation and linearity tests

In this section we explore the presence of a threshold-type nonlinearity in deviations from the LOOP. The test against a SETAR model requires the input of the parameters in the linear and nonlinear model. Hence, in this section we briefly describe the estimation process and the linearity test results.

We start by specifying a linear AR(p) model for each series of sectoral real exchange rates and choose the lag length according the Akaike criterion.[12] We assume that this gives us the appropriate lag order for each regime of the SETAR model. Following Hansen (1997), the range for the grid search is selected to contain the 15th and 85th percentile of the threshold variable. This ensures that the model is well identified for all thresholds and also that the results are not driven by a few outliers.[13] The SETAR model is estimated via a grid search over κ and d. As described above in Section 4, κ and d are selected through the minimization of the sum of squared residuals.

We next evaluate the adequacy of the estimated SETAR model using a battery of diagnostic tests on the estimated residuals. In particular, we start by examining the presence of serial correlation in the residuals using the Ljung-Box test. When serial correlation is found, we modify the model by increasing the value of the lag length (p). Then, we test for homoskedasticity of the residuals using the ARCH LM test. Neglected heteroskedasticity is potentially important in this context since it may lead to spurious rejection of the null hypothesis of linearity (see Franses and Van

[12] We prefer the Akaike information criterion over the Schwartz information criterion because the former leads to well behaved residuals both in the linear and the nonlinear models.

[13] After estimating the SETAR model for each of the sectoral real exchange rates, we made sure that the observations are evenly distributed across regimes. When we found very few observations in the outer regime, we trimmed the bottom and top 18% quantiles of the threshold variable.

Dijk, 2000). We also evaluate the normality assumption using the Jarque-Bera test. The rejection of normality may indicate that there are outliers, that the residuals are heteroskedastic or that there is some other source of misspecification. A final step involves examining whether the proposed model captures all the nonlinear features of the series. This can be analyzed by testing for remaining nonlinearity. In order to test for the presence of an additional regime in a SETAR model one needs to estimate the alternative multiple-regime model and evaluate it against the original SETAR model in a similar fashion as the nonlinear model is tested against a linear one. The estimation and evaluation of different multiple-regime SETAR models for 143 series can be very time consuming. Thus, we test for remaining nonlinearity using the Ramsey (1969) RESET test. This test leaves the type of nonlinearity under the alternative hypothesis unspecified but it is useful for our purposes to evaluate the potential presence of misspecification in our model. After running the diagnostic tests we make changes to our model when necessary.

The estimated SETAR model for each sectoral real exchange rate is presented in Table 3.A and Table 3.B shows the diagnostic tests. By and large, the estimated SETAR models pass the diagnostic tests. A relevant point to highlight is the violation of the normality assumption in the tobacco and communication sectors and, to a lesser extent, in the fuel sector. Thus, the estimated SETAR models for these sectors might be misspecified.

Using the parameters from the SETAR and linear models, the bootstrapped p-values for the Hansen test are calculated based on 1000 replications (see Hansen, 1997). The results from the linearity test, reported in Table 3.A, show that the null hypothesis of linearity is rejected in 104 out of 143 cases at a 10% level. At a 5% level the null hypothesis of linearity is rejected in 77 cases.

These results should not be taken as unsatisfactory because we are considering a wide range of sectors which have a different degree of tradability. In fact, the evidence of nonlinearities is quite heterogeneous across sectors. We would expect the LOOP to hold in sectors involving tradable homogeneous goods and characterized by the absence of government price controls. Results based on a 5% significance level show that nonlinearities are generally found in relatively homogeneous sectors such as fruits and are usually absent in sectors that are subject to government intervention, such as taxation (for example, alcoholic and nonalcoholic beverages). In sectors that involve a high degree of differentiation and high shipping costs such as fuel, sound equipment and vehicles, we find evidence of nonlinearities in the majority of countries. In contrast, nonlinearities are weak in furniture. In the case of low cost food sectors, such as bread and cereals and dairy products, evidence of nonlinearities is very significant. In sectors that involve low shipping costs and are relatively homogeneous, such as clothing and footwear, one would expect to find strong evidence of nonlinearities. Surprisingly, the evidence of nonlinearities in these sectors is mixed. The domestic appliances sector also exhibits some evidence of threshold behavior in spite of the difference in national standards. One interesting result is that we find significant evidence of nonlinearities in the case of hotels. It could be argued that since tourists are the 'buyers' of hotel services, they are traded internationally and this creates some scope for arbitrage. One would expect not to find evidence of threshold behavior in a sector such as tobacco given that it is subject to government intervention in the form of taxation or sale regulations. Interestingly, we find evidence of nonlinearities in this sector. A possible explanation for this result is that the estimated SETAR model is misspecified; for this sector there is a strong violation of the normality assumption.

7.2 SETAR model

Table 3.A reports the results for the SETAR model. From this table, it is clear that there is a wide variation in the results across countries and across sectors. Part of this is explained by the different nature of the sectors analyzed. Some sectors that involve high shipping costs and that are less homogeneous are clearly characterized by higher threshold bands. In addition, a country effect seems to be present. For a given sector, some countries exhibit relatively lower thresholds.

In discussing our results further in this Section, greater emphasis will be given to the behavior of tradable sectors or to sectors which at first glance appear to be tradable and we will focus mainly on those cases in which nonlinearities are significant.

7.2.1 Transaction costs

Estimated transaction costs differ enormously across sectors and countries. Relatively high transaction costs are observed for furniture, sound and vehicles, with average thresholds being 24%, 20% and 19%, respectively. Within these sectors, there is certain heterogeneity in the value of transaction costs across countries. Considering the countries for which nonlinearities are detected, the estimated $\widehat{\kappa}$ ranges from 10% to 35% for furniture, from 10% to 29% for sound and from 4% to 30% for vehicles. It seems reasonable to find high threshold bands for these sectors given their high shipping costs and their high degree of differentiation. The domestic appliances sector exhibits an average threshold band of 17%, ranging from 6% in Germany to 32% in Spain. The high transaction costs of this sector could be due to the barriers to arbitrage caused by differences in international regulatory standards.

In the case of clothing, the evidence of nonlinearities is significant and the behavior of the transaction costs band differs across countries. The lowest threshold band is found in Denmark, where the estimated $\widehat{\kappa}$ is 9%. High threshold bands are observed in Italy (32%), Belgium (25%) and Germany (19%). In the footwear sector, evidence of nonlinearities are found for all countries except Spain and the UK. The highest transaction costs correspond to Denmark (33%) and the lowest to the Netherlands (5%).

As far as the international fruit market is concerned, Denmark and the US appear to be highly integrated given that $\widehat{\kappa}$ is 2%. Other countries, such as Germany, Spain and the UK seem to be less integrated with estimated threshold of 11%, 12% and 15%, respectively.

Overall, the estimation results suggest that in some cases the value of the transaction costs is sector specific. This result is the most common finding mentioned in the literature (see Imbs et al., 2003). The sector effect is observed, for example, in the case of furniture, sound and vehicles, where thresholds are relatively high.

A result less mentioned in the literature is the country effect. By and large, there are 'low-threshold countries' such as Denmark, France, Germany, Netherlands and the UK and 'high-threshold countries' such as Belgium, Italy, Spain and Portugal. Average estimated transaction costs estimates for the former group range from 10% (UK and France) to 14% (Denmark and Germany). For the latter group, average threshold estimates range from 16% (Belgium) to 21% (Italy)[14].

In comparison to the work of Obstfeld and Taylor (1997) our estimated threshold bands are slightly higher, ranging from 10% to 21% (country averages), compared to the range reported by Obstfeld and Taylor of 7% to 10%. However, considering only European countries, the Obstfeld-Taylor range becomes 9% to 19%, which is closer to our estimated range. In addition, Obstfeld and Taylor (1997) use a much less disaggregated database and this could create another source of difference with respect to our estimated thresholds.

In line with the results described in Imbs et al. (2003), we find that the estimated thresholds are higher for goods with larger estimated persistence using a linear AR(p) model.

7.2.2 Half-lives

A standard measure of the speed of mean reversion is the half-life, which is the time it takes for half of the initial effect of a shock to dissipate. Table 4.A reports the estimated half-lives of deviations from the LOOP using two different methodologies. First, we compute the speed of mean reversion for each sectoral real exchange rate in the outer regime. Given that in the SETAR model the real exchange rate is at equilibrium within the band $[\kappa, -\kappa]$, it is reasonable to focus first on convergence to equilibrium relative to the band. In this case, the speed of convergence is given by the outer root of the TAR process, defined as $\rho = \sum_{p=1}^{P} \beta_p$. The half-life is calculated as in a linear model, i.e. $hl=\ln 0.5/\ln\rho$. Some studies emphasize that it is not clear whether the computation of half-lives for linear models is applicable for nonlinear models (see Lo and Zivot, 2001). However, all the studies based on a SETAR model use this measure (see, for example, Taylor, 2001) and thus we report it here for a simple comparison.

[14]Specifically, average estimated transaction costs are 10% for the UK and France, 11% for the Netherlands, 14% for Denmark and Germany, 16% for Belgium, 19% for Portugal and Spain and 21% for Italy.

While the estimated half-lives of the outer regime give some insights about the speed of mean reversion, this measure has the limitation that it does not consider the regime switching that takes place within and outside the band. Thus, in order to shed some light on the mean reverting properties of the sectoral real exchange rates we also calculate the half-lives using the generalized impulse response functions procedure described in Koop, Pesaran and Potter (1996). This complementary calculation, which considers the SETAR model as a whole, is important in the context of our model because there is an infinite half-life within the band and a half-life depending on ρ outside the band. A shock may cause the model to switch regimes and this adjustment is not captured using the first methodology. These results can be compared to those obtained using the first methodology and also to those previously reported in the literature to see if modeling nonlinearities helps to resolve the PPP puzzle of very slow real exchange rate adjustment (Rogoff, 1996).

One issue that arises in the context of nonlinear models is that the shape of impulse responses depends on the history of the system at the time of the shock, the size of the shock and the distribution of future exogenous innovations. Following Taylor et al. (2001), we compute the impulse response functions conditional on average initial history using Monte Carlo integration.[15]

For each sectoral real exchange rate, we estimate impulse responses conditional on average initial history for shocks of 10%, 20%, 30%, 40%, 50% and 60% and compute the half-lives for each shock size. This allows us to compare the persistence of large and small shock sizes. Table 4.A reports the half-lives for each shock as well as the half-lives implied by the conventional estimation procedure. Tables 4.B and 4.C show the average half-lives at a country and sectoral level.

From these tables it is clear that the speed of mean reversion depends on the size of the shock. Larger shocks mean-revert much faster than smaller shocks. This happens because the half-lives are dependent on the root of the outer regime as well as on the size of the threshold. Mean reversion is slower the closer the exchange rate is to equilibrium, given by the threshold bands. In addition, these results highlight the importance of calculating the half-lives using generalized impulse response functions. The conventional method gives a much faster speed of mean reversion. However, the latter result should be interpreted carefully, given that the conventional method considers only the outer regime and does not account for the regime shifts of the SETAR model.

Using country averages, half-lives are between 19 to 43 months for a 10% shock and between 10 to 25 months for a 60% shock. By contrast the half-lives computed using the conventional methodology range from 7 to 22 months.

The UK shows fast mean reversion, ranging from an average half-life of 19 months

[15] For a complete explanation of generalized impulse responses see Koop et al. (1996). A similar method as the one employed here but applied to an ESTAR model is presented and discussed in detail in Taylor et al (2001). Clarida and Taylor (2003) show how these methods may be employed to effect permanent-temporary decompositions within a nonlinear framework.

for a shock of 10% to one year for shocks of 60%; for shocks of 20% to 40%, the half-lives are between 14 and 12 months. The UK average half-life implied by the outer regime is 9 months. France exhibits considerably higher persistence, with average half-lives ranging from 33 months for a 10% shock to 25 months for 50% and 60% shocks. The average half-lives of Germany are very close to those of France, ranging from 34 months for a 10% shock to 20 months for a 60% shock.

These results shed some light on the PPP puzzle (Rogoff, 1996). In particular, our nonlinear models yield half-lives consistent with the 'consensus' estimates of 3 to 5 years only for small shocks taking place when the real exchange rate is close to equilibrium. For Germany, France, Italy, Netherlands and the UK, even small shocks of 10% have a half-life of under 3 years. For shocks larger than 20% all of the countries exhibit a half-life under 3 years.

Our results also show that the half-life of deviations are considerably reduced when fitting a nonlinear model with respect to a linear AR(p) model. By and large, a linear model yields estimated speeds of adjustment consistent with the PPP puzzle. The half-lives implied by the linear model are between 20 and 230 months (country averages).[16]

The half-lives at the country level display heterogeneity across sectors. From Table 4.C it is clear that the pattern of larger shocks adjusting faster is also very marked at the sectoral level, however. Relatively high persistence is observed in furniture and vehicles (for all shock sizes), followed by alcoholic and nonalcoholic beverages, clothing and footwear. The sectors with the lowest persistence for all shocks sizes are fruits, tobacco, sound and fuel.

It is difficult to compare these results with those reported in the related literature given that studies using SETAR models for disaggregated data compute the half-lives in the outer regime. Obstfeld and Taylor (1997), for example, estimate half-lives ranging from 3 to 19 months. These results are in line with those reported here for the conventional (outer-regime) calculation. Interestingly, our estimated half-lives for larger shocks are relatively lower than the ones reported in studies where data at lower frequency was used (Sarno, Taylor and Chowdhury, 2002, for example, find an average estimated half-life of 6 quarters). These results underline the relevance of modelling deviations from the LOOP in a nonlinear framework using data at higher frequency and the importance of calculating half-lives taking into account the SETAR model as a whole using generalized impulse response functions.

7.2.3 The delay parameter

The estimation results for the SETAR model suggest that the speed at which agents react to deviations from the LOOP is heterogeneous across sectors and across countries for a given sector. In principle, one should not expect that deviations from the

[16] The results of the linear model estmation are not presented here, in order to conserve space, but are available from the authors upon request.

LOOP to exhibit a high degree of stickiness (large values of d). In fact, in 48 out of the 143 cases examined, our estimation results report a delay parameter equal to 1 and most of the estimated values of d are equal to 2 or 3. Overall, the modal estimate of the delay parameter is 3.

Given that the estimated delay parameter differs from 1 in a majority of cases, it seems reasonable to estimate it within the grid search. Obstfeld and Taylor (1997) restrict it to equal 1. However, we should not expect the results to vary considerably with different values of the delay parameter.

As a robustness check, the model was estimated restricting d to equal unity (results not presented here but available from the authors upon request). It turns out that the estimated parameters do not change considerably from one specification to the other. The sum of squared residuals also remains very stable in the different specifications. This is a desirable result because it means that the estimated parameters are not determined by accidental features of the data.

8 Conclusion

In this study we find that when modelling deviations from the LOOP in a nonlinear fashion we find evidence supportive of mean reversion in sectoral real exchange rates. There is, however, evidence of considerable heterogeneity in transaction costs across both sectors and countries. Using the US dollar as the reference currency, the estimated threshold bands range from 10% to 21% (measured as country averages).

In order to shed some light on the mean-reverting properties of the sectoral real exchange rates we consider the regime switching that takes place within and outside the band in the SETAR model and we compute the half-lives using generalized impulse response functions. Our results show that the speed of mean reversion depends on the size of the shock: larger shocks mean-revert much faster than smaller ones. For larger shocks, country-average half-lives range between 10 and 25 months, well below the 'consensus estimates' of three to five years highlighted by Rogoff (1996) at the aggregate level. In our research, we start by observing that the conventional estimation approach to calculate half-lives in a SETAR framework yields a much faster speed of mean reversion but that this measure only considers the outer band on the SETAR model and consequently one may need to be careful in the interpretation of results. In addition, our results also show that the half-life of deviations are considerably reduced when fitting a nonlinear model with respect to a linear AR(p) model. The half-lives implied by the linear model are between 20 and 230 months (country averages). The SETAR model half-lives are smaller than the consensus estimates of three to five years and also smaller than the ones found in other studies that estimate nonlinear models with data at a lower frequency.

The time taken for economic agents to react to deviations from the LOOP varies across sectors and countries. The modal value of the delay parameter is 3. This may suggest that the delay parameter should be estimated and not restricted to be equal to unity as has been done in previous studies, although our results are robust and the estimated parameters do not change considerably when d is restricted to equal unity.

The agenda for future research in this area is large. For example, the present analysis reveals the importance of sectoral heterogeneity. In this way it contributes to the findings of Imbs et al. (2005) who suggest that slow speeds of adjustment may be due to an aggregation bias arising from the heterogeneous speed of adjustment of disaggregated relative prices. These authors reach this conclusion using linear panel data estimators. It would therefore be interesting to extend the present analysis using nonlinear panel data methods. In his way we could allow both for the presence of sectoral heterogeneity and nonlinear adjustment.

A Appendix: Tables

Table 1.A. Dickey-Fuller Test

	BE	**DK**	**DE**	**FR**	**IT**	**NL**	**PT**	**SP**	**UK**
bread	-1.88	-1.51	-1.92	-2.01	-1.82	-2.18	-1.53	-1.22	-2.91 **
meat	-1.90	-2.00	-2.00	-1.82	-2.13	-2.11	-2.47	-1.69	-3.74 ***
dairy	-1.65	-1.57	-1.72	-1.62	-1.62	-1.76	-2.17	-1.37	-2.35
fruit	-3.17 **	-3.11 **	-5.02 ***	-2.81 *	-1.84	-2.58 *	-2.67 *	-2.04	-3.09 **
tobac	-1.93	-2.17	-2.08	-1.85	-1.59	-2.17	-1.96	-2.81 *	-2.89 **
alco	-1.79	-1.99	-1.99	-1.91	-1.72	-2.05	-1.05	-1.19	-2.18
cloth	-0.96	-1.85	-1.41	-1.17	-1.43	-3.29 **	-0.98	-1.10	-3.40 **
foot	-1.15	-1.19	-1.27	-1.21	-1.32	-3.06 **	-1.00	-1.13	-3.03 **
fuel	-2.49	-1.28	-1.81	-1.60	-1.63	-1.87	-1.58	-1.77	-2.09
furniture	-1.37	-1.25	-1.41	-1.26	-1.50	-1.63	-0.89	-1.20	-2.50
dom	-1.37	-1.39	-1.45	-1.44	-1.44	-1.45	-1.11	-1.15	-2.75 *
vehicles	-1.57	-1.24	-1.22	-1.34	-1.77	-1.44	-0.71	-1.21	-2.14
comm	-2.41	-1.74	-2.38	-3.50 **	-2.69 *	-2.06	-4.05 ***	-2.13	-3.50 **
sound	-1.46	-1.55	-1.64	-1.56	-1.58	-1.58	NA	-1.43	-2.00
books	-1.47	-1.32	-1.77	-1.96	-1.32	-2.08	-1.19	-1.48	-2.37
hotels	-2.50	-2.85 *	-2.79 *	-2.58 *	-2.15	-2.95 **	-2.14	-1.68	-3.66 ***

Notes: The table shows the Dickey-Fuller test statistic. The critical values are -2.58, -2.89 and -3.51 for the 10%, 5% and 1% significance levels respectively. We are testing the null hypothesis of unit root against an alternative of stationarity. *, ** and *** denote statistical stignificance at the 10%, 5% and 1% signifcance levels respectively. Abbreviations for the countries are as follows: BE (Belgium), DK (Denmark), DE (Germany), FR (France), IT (Italy), NL (Netherlands), PT (Portugal), SP (Spain), UK (United Kingdom).

Table 1.B. Enders and Granger Test

	BE	DK	DE	FR	IT	NL	PT	SP	UK
bread	3.47 *	2.15	1.52	1.92	2.00	2.48	0.56	1.10	7.50 ***
meat	1.16	1.23	1.04	0.98	1.24	1.36	1.28	2.59	5.90 ***
dairy	2.66	0.79	0.63	1.30	2.34	1.78	1.57	0.63	3.21 **
fruit	4.79 **	5.93 ***	6.95 ***	3.28 *	2.74	4.45 **	3.64 *	2.46	3.19 *
tobac	1.71	5.14 **	4.23 **	1.67	2.43	4.13 **	1.11	4.68 **	3.52 *
alco	1.45	1.27	1.28	1.49	0.77	2.10	0.80	0.42	2.02
cloth	0.80	2.17	0.44	0.50	1.36	6.56 ***	0.17	0.51	7.60 ***
foot	0.34	0.36	0.58	0.55	2.27	5.13 ***	0.35	0.47	7.21 ***
fuel	3.64 *	0.31	1.69	1.09	1.58	2.22	1.17	1.64	2.86
furniture	0.67	1.77	1.20	0.67	3.75 *	1.10	0.52	0.94	5.44 ***
dom	0.79	0.79	0.86	1.00	2.28	1.19	0.48	1.61	5.87 ***
vehicles	0.79	0.75	0.72	0.90	1.09	0.72	0.31	1.73	2.13
comm	7.19 **	2.32	6.02 ***	10.37 ***	6.61 ***	6.33 ***	8.80 ***	3.61 *	8.81 ***
sound	0.84	0.99	1.19	1.33	2.21	0.79	NA	1.16	2.53
books	1.40	1.23	1.69	3.32 *	1.98	2.39	0.34	0.58	2.97
hotels	5.76 ***	5.18 **	4.80 **	4.67 **	3.37 *	5.11 ***	1.44	1.73	8.27 ***

Notes: The table shows the Enders and Granger test statistic. The critical values were calculated by simulation on the basis of 10,000 replications and T=200 for each SETAR model corresponding to each series as described in Enders and Granger (1998). We are testing the null hypothesis of unit root against an alternative of stationarity with threshold adjustment. *, ** and *** denote statistical stignificance at the 10%, 5% and 1% signifcance levels respectively. Abbreviations for the countries are as follows: BE (Belgium), DK (Denmark), DE (Germany), FR (France), IT (Italy), NL (Netherlands), PT (Portugal), SP (Spain), UK (United Kingdom).

Table 2. Power of the Unit Root Test
(1% and 5% significance levels)

	Dickey-Fuller Test		Enders and Granger Test	
	p=0.01	p=0.05	p=0.01	p=0.05
ρ=0.80	51.89	87.9	57.34	91.2
ρ=0.90	9.06	32.33	15.19	36.18
ρ=0.95	2.78	12.38	7.96	17.43
ρ=0.96	1.93	9.94	5.64	13.27
ρ=0.97	1.44	8.14	4.92	12.41
ρ=0.98	1.4	6.83	4.87	11.74

Notes: The table shows the power of the Dickey Fuller and the Enders and Granger tests at 1% and 5% significance levels. The results were caluclated on the basis of 10,000 replications and T=200. In the case of the Dickey-Fuller test, we assumed that the true process follows an AR(1) model with autoregressive parameter ρ. In the case of the Enders and Granger test we assumed that the process follows a SETAR (1,2,1) model similar to that in equation 6 with κ=0.10 and outer root ρ.

Table 3.A. SETAR estimation results

	κ	ρ	d	lag	p-value
			bread		
BE	0.19	0.95	4	4	0.036
DK	0.21	0.95	4	5	0.251
DE	0.05	0.97	2	2	0.119
FR	0.04	0.97	3	5	0.334
IT	0.17	0.89	4	4	0.019
NL	0.03	0.96	1	2	0.258
PT	0.15	0.97	2	4	0.000
SP	0.37	0.92	1	6	0.059
UK	0.14	0.83	3	4	0.009
			meat		
BE	0.15	0.94	3	5	0.208
DK	0.04	0.97	1	3	0.442
DE	0.03	0.97	1	2	0.072
FR	0.04	0.97	1	2	0.094
IT	0.03	0.96	2	3	0.053
NL	0.02	0.97	2	2	0.204
PT	0.10	0.88	2	2	0.018
SP	0.27	0.87	5	5	0.021
UK	0.04	0.91	3	3	0.043
			dairy		
BE	0.22	0.91	4	4	0.011
DK	0.20	0.94	1	5	0.077
DE	0.20	0.94	1	3	0.128
FR	0.05	0.97	1	4	0.072
IT	0.22	0.86	3	4	0.038
NL	0.07	0.96	3	3	0.042
PT	0.03	0.97	2	2	0.016
SP	0.10	0.98	1	3	0.016
UK	0.03	0.96	2	4	0.027
			fruit		
BE	0.16	0.93	6	8	0.044
DK	0.02	0.92	2	2	0.009
DE	0.11	0.95	10	12	0.076
FR	0.18	0.91	3	8	0.023
IT	0.22	0.83	1	2	0.024
NL	0.14	0.95	1	8	0.688
PT	0.18	0.84	8	9	0.044
SP	0.12	0.93	1	1	0.046
UK	0.15	0.92	1	12	0.069

continued next page...

...table 3.A. continued

	κ	ρ	d	*lag*	p-value
			tobac		
BE	0.03	0.97	3	11	0.203
DK	0.03	0.97	1	4	0.022
DE	0.19	0.78	1	3	0.097
FR	0.08	0.97	2	2	0.054
IT	0.20	0.76	1	2	0.003
NL	0.12	0.90	2	4	0.024
PT	0.29	0.82	2	2	0.010
SP	0.05	0.95	1	2	0.097
UK	0.15	0.89	1	2	0.049
			alco		
BE	0.05	0.97	1	2	0.094
DK	0.09	0.94	1	4	0.018
DE	0.17	0.95	4	4	0.029
FR	0.02	0.97	1	4	0.072
IT	0.07	0.97	2	4	0.032
NL	0.04	0.97	1	2	0.173
PT	0.30	0.98	2	2	0.010
SP	0.11	0.98	1	5	0.128
UK	0.08	0.94	4	4	0.060
			cloth		
BE	0.25	0.97	4	5	0.068
DK	0.09	0.97	2	8	0.086
DE	0.19	0.96	4	4	0.061
FR	0.08	0.98	1	4	0.034
IT	0.32	0.92	2	4	0.006
NL	0.03	0.93	4	8	0.853
PT	0.14	0.98	2	3	0.017
SP	0.08	0.98	1	5	0.224
UK	0.02	0.93	3	7	0.296
			foot		
BE	0.27	0.96	3	5	0.079
DK	0.33	0.89	5	7	0.022
DE	0.22	0.96	4	4	0.052
FR	0.07	0.98	5	5	0.063
IT	0.27	0.95	5	5	0.008
NL	0.05	0.92	4	9	0.002
PT	0.12	0.98	3	3	0.038
SP	0.07	0.98	1	6	0.124
UK	0.15	0.90	2	3	0.119

continued next page...

...table 3.A. continued

	κ	ρ	d	lag	p-value
			fuel		
BE	0.04	0.95	2	5	0.206
DK	0.29	0.84	9	10	0.000
DE	0.04	0.97	2	2	0.122
FR	0.05	0.97	2	4	0.098
IT	0.25	0.88	2	2	0.016
NL	0.06	0.96	1	2	0.220
PT	0.23	0.87	1	2	0.004
SP	0.21	0.84	2	2	0.009
UK	0.08	0.95	1	4	0.019
			furniture		
BE	0.27	0.96	4	4	0.090
DK	0.24	0.97	2	3	0.047
DE	0.18	0.96	1	2	0.056
FR	0.10	0.98	2	4	0.028
IT	0.32	0.73	3	10	0.168
NL	0.24	0.95	4	4	0.140
PT	0.35	0.96	1	2	0.017
SP	0.25	0.97	1	5	0.159
UK	0.20	0.86	8	9	0.210
			dom		
BE	0.10	0.98	1	5	0.188
DK	0.08	0.98	1	2	0.003
DE	0.06	0.98	1	2	0.014
FR	0.06	0.98	3	4	0.098
IT	0.27	0.81	1	5	0.058
NL	0.11	0.96	2	2	0.026
PT	0.37	0.87	1	4	0.134
SP	0.32	0.76	3	4	0.039
UK	0.17	0.78	4	4	0.001
			vehicles		
BE	0.22	0.94	4	5	0.132
DK	0.23	0.97	1	2	0.004
DE	0.19	0.97	1	3	0.007
FR	0.23	0.94	4	5	0.118
IT	0.15	0.91	2	4	0.002
NL	0.17	0.97	1	3	0.207
PT	0.17	0.98	1	2	0.010
SP	0.30	0.90	3	5	0.042
UK	0.04	0.96	2	4	0.029

continued next page...

...table 3.A. continued

	κ	ρ	d	*lag*	p-value
			comm		
BE	0.09	0.95	2	2	0.003
DK	0.03	0.98	2	2	0.013
DE	0.05	0.96	2	2	0.121
FR	0.09	0.95	4	4	0.003
IT	0.07	0.92	1	2	0.033
NL	0.17	0.95	1	2	0.114
PT	0.03	0.94	3	4	0.057
SP	0.26	0.91	1	2	0.000
UK	0.06	0.94	2	2	0.217
			sound		
BE	0.21	0.93	4	4	0.009
DK	0.10	0.97	2	2	0.007
DE	0.24	0.94	3	4	0.024
FR	0.12	0.96	4	4	0.172
IT	0.29	0.76	1	5	0.053
NL	0.24	0.82	4	4	0.020
SP	0.20	0.93	1	6	0.114
UK	0.17	0.76	3	4	0.003
			books		
BE	0.05	0.98	1	4	0.150
DK	0.20	0.96	3	4	0.007
DE	0.19	0.94	4	4	0.019
FR	0.17	0.94	4	4	0.019
IT	0.24	0.84	2	4	0.014
NL	0.15	0.94	4	4	0.002
PT	0.34	0.88	1	4	0.000
SP	0.06	0.98	2	6	0.134
UK	0.02	0.96	3	5	0.538
			hotels		
BE	0.22	0.90	3	12	0.000
DK	0.10	0.86	11	12	0.042
DE	0.17	0.78	4	12	0.039
FR	0.19	0.91	4	12	0.008
IT	0.21	0.79	6	9	0.270
NL	0.16	0.82	4	12	0.000
PT	0.04	0.98	1	4	0.018
SP	0.27	0.92	9	9	0.013
UK	0.10	0.91	6	12	0.862

Notes: This table shows the results from the estimation of the SETAR (p, 2, d) model in equation (6). κ is the value of the threshold, ρ is the outer root of the TAR process, d is the delay parameter and *lag* is the lag length. The estimation of κ, ρ and d is done simultaneously via a grid search over κ and d as is described in section 3. The p-value is the marginal significance level of the Hansen (1997) linearity test. Abbreviations are the same as in Table 1.

Table 3.B. Diagnostic Tests

	BE	**DK**	**DE**	**FR**	**IT**	**NL**	**PT**	**SP**	**UK**
					bread				
Q(12)	6.965	3.746	5.719	2.606	5.722	5.068	5.702	5.658	7.103
	(0.223)	(0.290)	(0.768)	(0.456)	(0.334)	(0.828)	(0.336)	(0.059)*	(0.213)
ARCH(4)	2.107	1.801	1.847	1.205	0.970	1.187	2.185	4.578	8.284
	(0.716)	(0.772)	(0.764)	(0.877)	(0.914)	(0.880)	(0.702)	(0.333)	(0.082)*
ARCH(8)	3.293	4.328	7.466	3.683	6.845	7.673	3.166	4.597	10.286
	(0.915)	(0.826)	(0.487)	(0.885)	(0.553)	(0.466)	(0.924)	(0.800)	(0.246)
JB	0.516	0.772	0.459	4.537	0.493	0.124	3.575	1.218	13.945
	(0.773)	(0.680)	(0.795)	(0.103)	(0.782)	(0.940)	(0.182)	(0.544)	(0.000)***
RESET	1.046	0.519	1.596	0.606	1.450	1.469	0.928	0.972	1.170
	(0.373)	(0.669)	(0.205)	(0.612)	(0.229)	(0.232)	(0.428)	(0.407)	(0.322)
					meat				
Q(12)	3.653	4.067	7.106	7.278	9.709	5.614	10.376	5.073	15.100
	(0.301)	(0.772)	(0.626)	(0.608)	(0.206)	(0.778)	(0.321)	(0.167)	(0.236)
ARCH(4)	1.825	5.125	2.145	2.337	1.098	2.824	0.159	2.761	9.893
	(0.768)	(0.275)	(0.709)	(0.674)	(0.895)	(0.588)	(0.690)	(0.599)	(0.052)*
ARCH(8)	2.323	6.991	3.570	3.111	7.058	5.626	0.874	3.186	15.187
	(0.969)	(0.538)	(0.894)	(0.927)	(0.530)	(0.689)	(0.928)	(0.922)	(0.066)*
JB	3.852	0.887	1.091	4.433	2.890	0.296	9.608	4.440	4.323
	(0.146)	(0.642)	(0.579)	(0.111)	(0.236)	(0.863)	(0.008)***	(0.109)	(0.115)
RESET	0.333	0.352	0.661	0.633	1.203	0.224	0.888	0.935	1.532
	(0.855)	(0.704)	(0.518)	(0.532)	(0.310)	(0.800)	(0.413)	(0.425)	(0.207)
					dairy				
Q(12)	7.920	6.247	4.589	6.363	8.821	4.580	9.061	5.415	8.442
	(0.161)	(0.100)	(0.710)	(0.272)	(0.116)	(0.869)	(0.432)	(0.609)	(0.134)
ARCH(4)	2.803	2.386	2.110	1.068	4.240	3.528	6.866	1.245	6.747
	(0.591)	(0.665)	(0.716)	(0.899)	(0.375)	(0.474)	(0.143)	(0.871)	(0.150)
ARCH(8)	4.367	3.213	6.952	2.996	13.309	14.112	9.718	8.494	8.754
	(0.823)	(0.920)	(0.542)	(0.935)	(0.102)	(0.079)*	(0.285)	(0.387)	(0.363)
JB	2.839	2.951	2.202	5.920	3.939	1.221	2.324	0.806	16.364
	(0.242)	(0.229)	(0.333)	(0.062)*	(0.140)	(0.543)	(0.312)	(0.668)	(0.000)***
RESET	1.04373	1.830	1.054	1.250	1.861	0.327	1.366	2.144	1.901
	(0.374)	(0.143)	(0.370)	(0.293)	(0.137)	(0.721)	(0.257)	(0.077)*	(0.131)
					fruit				
Q(12)	5.536	6.176	10.177	8.880	16.029	3.424	2.929	4.147	1.293
	(0.738)	(0.722)	(0.600)	(0.713)	(0.166)	(0.000)***	(0.032)**	(0.246)	(0.000)***
ARCH(4)	7.476	0.648	1.975	3.953	3.104	1.290	4.934	2.730	1.704
	(0.113)	(0.958)	(0.740)	(0.412)	(0.541)	(0.863)	(0.394)	(0.604)	(0.790)
ARCH(8)	10.970	1.082	9.560	5.087	6.721	7.960	18.811	7.815	7.72
	(0.203)	(0.998)	(0.297)	(0.748)	(0.567)	(0.437)	(0.216)	(0.452)	(0.461)
JB	4.148	0.967	1.427	0.157	2.188	0.080	3.954	24.436	3.904
	(0.126)	(0.617)	(0.490)	(0.924)	(0.335)	(0.961)	(0.138)	(0.000)***	(0.142)
RESET	0.657	0.943	1.62	0.418	1.899	1.003	3.917	0.285	2.239
	(0.708)	(0.333)	(0.186)	(0.740)	(0.152)	(0.393)	(0.096)*	(0.594)	(0.085)*

continued next page...

...table 3.B. continued

	BE	**DK**	**DE**	**FR**	**IT**	**NL**	**PT**	**SP**	**UK**
					tobac				
Q(12)	1.602	10.662	3.7353	5.975	6.752	3.398	12.820	7.028	4.340
	(0.999)	(0.058)*	(0.810)	(0.742)	(0.663)	(0.639)	(0.171)	(0.634)	(0.502)
ARCH(4)	1.082	0.954	1.210	2.949	0.953	0.780	0.657	1.534	1.147
	(0.897)	(0.917)	(0.876)	(0.566)	(0.917)	(0.941)	(0.956)	(0.821)	(0.887)
ARCH(8)	1.597	1.291	1.684	2.295	2.497	2.846	2.077	5.388	10.551
	(0.991)	(0.996)	(0.989)	(0.971)	(0.962)	(0.944)	(0.979)	(0.715)	(0.228)
JB	94.013	118.081	51.9434	98.873	138.465	57.317	38.409	76.624	44.646
	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
RESET	1.559	1.274	1.829	0.346	2.830	0.430	0.698	1.996	1.396
	(0.114)	(0.284)	(0.083)*	(0.708)	(0.061)*	(0.731)	(0.404)	(0.138)	(0.245)
					alco				
Q(12)	10.507	12.196	6.005	5.615	7.885	6.193	9.174	7.908	6.652
	(0.311)	(0.158)	(0.306)	(0.345)	(0.163)	(0.720)	(0.421)	(0.543)	(0.248)
ARCH(4)	6.710	2.135	5.588	1.426	0.928	4.522	1.387	3.762	10.355
	(0.152)	(0.711)	(0.232)	(0.840)	(0.920)	(0.340)	(0.846)	(0.439)	(0.135)
ARCH(8)	12.530	2.484	9.452	3.678	4.105	16.495	2.999	7.461	11.595
	(0.129)	(0.962)	(0.306)	(0.885)	(0.848)	(0.136)	(0.934)	(0.488)	(0.270)
JB	0.250	19.519	1.073	4.695	2.389	0.586	23.494	0.212	11.995
	(0.882)	(0.000)***	(0.585)	(0.096)*	(0.303)	(0.746)	(0.000)***	(0.899)	(0.002)***
RESET	0.413	1.200	0.219	0.197	0.781	1.790	0.585	0.208	0.729
	(0.521)	(0.311)	(0.883)	(0.898)	(0.506)	(0.170)	(0.558)	(0.891)	(0.536)
					cloth				
Q(12)	3.199	19.150	2.645	1.859	4.615	4.786	10.386	6.656	19.964
	(0.362)	(0.085)*	(0.754)	(0.868)	(0.465)	(0.310)	(0.168)	(0.155)	(0.068)*
ARCH(4)	4.495	6.918	5.571	2.244	1.327	7.082	2.609	2.938	12.455
	(0.343)	(0.118)	(0.234)	(0.691)	(0.857)	(0.132)	(0.625)	(0.568)	(0.014)**
ARCH(8)	5.326	12.507	12.746	5.234	4.421	12.872	2.645	4.120	18.439
	(0.722)	(0.130)	(0.121)	(0.732)	(0.817)	(0.131)	(0.955)	(0.846)	(0.018)**
JB	1.377	0.383	3.213	5.605	4.582	2.283	4.320	0.859	0.326
	(0.502)	(0.826)	(0.201)	(0.061)*	(0.101)	(0.319)	(0.110)	(0.651)	(0.850)
RESET	0.439	1.993	0.496	0.859	0.766	0.840	0.010	0.858	0.530
	(0.780)	(0.116)	(0.685)	(0.463)	(0.514)	(0.474)	(0.990)	(0.464)	(0.682)
					foot				
Q(12)	5.871	7.067	4.515	3.963	4.753	1.636	7.466	4.363	7.099
	(0.118)	(0.853)	(0.478)	(0.266)	(0.191)	(0.802)	(0.382)	(0.113)	(0.419)
ARCH(4)	5.865	6.910	7.042	2.287	3.551	0.751	2.022	3.661	8.460
	(0.209)	(0.141)	(0.134)	(0.683)	(0.470)	(0.945)	(0.732)	(0.454)	(0.076)*
ARCH(8)	6.592	15.242	11.512	8.331	5.955	6.700	3.470	6.300	9.173
	(0.581)	(0.055)*	(0.174)	(0.402)	(0.652)	(0.569)	(0.902)	(0.614)	(0.328)
JB	1.112	0.132	2.204	6.138	1.905	1.892	0.031	0.005	0.133
	(0.574)	(0.936)	(0.332)	(0.056)*	(0.386)	(0.388)	(0.703)	(0.997)	(0.936)
RESET	0.801	1.492	0.254	0.4323	1.661	2.328	0.441	0.803	2.151
	(0.526)	(0.218)	(0.858)	(0.730)	(0.160)	(0.058)*	(0.644)	(0.494)	(0.095)*

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...table 3.B. continued

	BE	**DK**	**DE**	**FR**	**IT**	**NL**	**PT**	**SP**	**UK**
					fuel				
Q(12)	12.903	2.046	6.306	3.647	5.974	12.228	6.651	4.601	10.629
	(0.167)	(0.360)	(0.709)	(0.601)	(0.743)	(0.201)	(0.673)	(0.868)	(0.561)
ARCH(4)	0.637	0.753	2.033	2.176	3.347	3.048	6.794	1.977	12.888
	(0.959)	(0.945)	(0.730)	(0.703)	(0.501)	(0.550)	(0.147)	(0.740)	(0.012)**
ARCH(8)	8.691	4.980	10.747	9.426	7.938	7.182	12.877	3.550	14.365
	(0.369)	(0.760)	(0.216)	(0.308)	(0.440)	(0.517)	(0.116)	(0.895)	(0.073)*
JB	29.858	5.584	17.835	8.552	0.213	0.471	4.443	11.430	5.067
	(0.000)***	(0.061)*	(0.000)***	(0.014)**	(0.899)	(0.790)	(0.108)	(0.003)***	(0.079)*
RESET	0.291	1.727	0.393	0.269	2.501	0.752	1.232	1.694	0.686
	(0.883)	(0.163)	(0.675)	(0.848)	(0.060)*	(0.473)	(0.294)	(0.137)	(0.562)
					furniture				
Q(12)	9.119	9.662	8.290	8.891	5.043	6.589	18.058	7.491	4.265
	(0.104)	(0.209)	(0.308)	(0.113)	(0.080)*	(0.253)	(0.114)	(0.058)*	(0.000)***
ARCH(4)	4.079	5.820	6.229	3.168	3.856	5.267	0.618	1.487	14.297
	(0.395)	(0.213)	(0.183)	(0.530)	(0.426)	(0.261)	(0.961)	(0.829)	(0.006)***
ARCH(8)	6.699	9.612	15.549	5.138	8.534	12.520	0.843	6.594	18.999
	(0.569)	(0.293)	(0.049)**	(0.743)	(0.383)	(0.129)	(0.999)	(0.581)	(0.015)**
JB	1.017	0.350	0.200	2.134	0.060	0.585	3.461	0.147	7.767
	(0.601)	(0.839)	(0.905)	(0.344)	(0.971)	(0.746)	(0.177)	(0.929)	(0.021)**
RESET	0.278	0.627	0.998	0.397	0.308	0.679	0.265	0.813	0.940
	(0.842)	(0.535)	(0.370)	(0.756)	(0.820)	(0.508)	(0.768)	(0.488)	(0.422)
					dom				
Q(12)	5.008	6.065	6.328	3.571	4.585	5.830	6.155	6.166	7.071
	(0.171)	(0.733)	(0.707)	(0.613)	(0.205)	(0.757)	(0.291)	(0.290)	(0.215)
ARCH(4)	2.849	3.393	4.707	2.595	1.712	2.875	1.716	2.640	9.554
	(0.583)	(0.494)	(0.319)	(0.628)	(0.789)	(0.579)	(0.788)	(0.620)	(0.049)**
ARCH(8)	2.906	6.625	6.379	2.971	2.670	8.293	3.503	3.655	11.395
	(0.940)	(0.578)	(0.605)	(0.936)	(0.953)	(0.405)	(0.899)	(0.887)	(0.180)
JB	0.205	0.327	0.492	6.298	2.260	0.405	28.641	0.299	3.954
	(0.903)	(0.849)	(0.782)	(0.043)**	(0.323)	(0.817)	(0.000)***	(0.861)	(0.138)
RESET	0.140	1.279	0.873	0.459	1.911	1.025	0.974	1.449	1.381
	(0.967)	(0.281)	(0.419)	(0.711)	(0.129)	(0.360)	(0.406)	(0.230)	(0.250)
					vehicles				
Q(12)	4.474	3.972	4.401	1.556	7.705	3.709	22.147	3.894	6.755
	(0.215)	(0.913)	(0.733)	(0.669)	(0.173)	(0.813)	(0.036)**	(0.273)	(0.240)
ARCH(4)	2.027	2.384	3.433	3.233	3.331	2.251	0.503	4.176	16.842
	(0.731)	(0.666)	(0.488)	(0.520)	(0.504)	(0.690)	(0.973)	(0.383)	(0.002)***
ARCH(8)	2.223	4.377	3.869	4.613	4.145	8.083	19.425	6.605	19.861
	(0.973)	(0.822)	(0.869)	(0.798)	(0.844)	(0.425)	(0.013)**	(0.580)	(0.011)**
JB	1.326	0.061	5.286	14.814	3.289	3.569	4.221	2.172	5.846
	(0.515)	(0.970)	(0.071)*	(0.001)***	(0.193)	(0.168)	(0.120)	(0.338)	(0.054)*
RESET	0.420	0.077	0.173	0.474	1.139	0.689	2.256	1.772	1.929
	(0.794)	(0.926)	(0.914)	(0.755)	(0.334)	(0.503)	(0.107)	(0.154)	(0.126)

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...table 3.B. continued

	BE	**DK**	**DE**	**FR**	**IT**	**NL**	**PT**	**SP**	**UK**
					comm				
Q(12)	4.487	11.504	8.930	2.678	5.139	7.239	7.983	6.397	5.139
	(0.877)	(0.243)	(0.444)	(0.750)	(0.822)	(0.612)	(0.157)	(0.700)	(0.822)
ARCH(4)	6.594	1.572	6.157	3.414	0.748	3.153	3.276	2.003	0.748
	(0.159)	(0.814)	(0.188)	(0.491)	(0.945)	(0.533)	(0.513)	(0.735)	(0.945)
ARCH(8)	7.257	12.888	13.124	20.038	21.472	4.788	5.912	2.888	21.472
	(0.509)	(0.116)	(0.108)	(0.010)**	(0.006)***	(0.780)	(0.657)	(0.941)	(0.007)***
JB	17.680	0.852	1.155	26.703	10.178	1.237	68.953	51.588	10.178
	(0.000)***	(0.653)	(0.561)	(0.000)***	(0.006)***	(0.539)	(0.000)***	(0.000)***	(0.006)***
RESET	(0.267)	2.170	1.231	0.545	0.996	1.213	0.076	0.729	0.996
	(0.606)	(0.117)	(0.294)	(0.652)	(0.371)	(0.299)	(0.973)	(0.484)	(0.371)
					sound				
Q(12)	8.981	11.727	6.953	6.639	10.074	6.067	-	7.138	5.418
	(0.110)	(0.229)	(0.224)	(0.249)	(0.610)	(0.300)	-	(0.129)	(0.367)
ARCH(4)	2.568	3.823	3.392	2.66	0.204	5.015	-	4.447	4.270
	(0.633)	(0.430)	(0.494)	(0.616)	(0.995)	(0.286)	-	(0.349)	(0.371)
ARCH(8)	4.672	8.454	6.945	5.163	6.049	11.223	-	7.179	5.892
	(0.792)	(0.390)	(0.543)	(0.740)	(0.642)	(0.189)	-	(0.517)	(0.660)
JB	0.046	0.765	1.822	7.164	1.019	0.206	-	0.771	3.227
	(0.977)	(0.682)	(0.402)	(0.028)**	(0.601)	(0.902)	-	(0.680)	(0.199)
RESET	(1.195)	1.439	0.237	0.524	1.111	1.237	-	0.868	0.048
	(0.313)	(0.239)	(0.870)	(0.666)	(0.346)	(0.297)	-	(0.459)	(0.986)
					books				
Q(12)	5.468	4.617	5.344	5.238	8.219	3.921	6.516	12.974	15.213
	(0.361)	(0.464)	(0.375)	(0.388)	(0.768)	(0.561)	(0.259)	(0.371)	(0.230)
ARCH(4)	2.945	1.483	3.502	2.399	4.497	3.751	1.387	1.692	6.361
	(0.567)	(0.830)	(0.478)	(0.663)	(0.340)	(0.441)	(0.846)	(0.792)	(0.174)
ARCH(8)	3.800	2.952	7.419	2.057	5.326	6.224	1.703	5.955	8.793
	(0.875)	(0.937)	(0.492)	(0.979)	(0.722)	(0.622)	(0.989)	(0.652)	(0.360)
JB	0.510	3.846	2.944	5.208	0.930	1.292	68.231	3.200	1.806
	(0.775)	(0.146)	(0.229)	(0.074)*	(0.628)	(0.524)	(0.000)***	(0.200)	(0.405)
RESET	0.248	0.390	0.273	0.355	0.878	0.661	2.247	1.369	1.113
	(0.863)	(0.761)	(0.845)	(0.785)	(0.454)	(0.577)	(0.084)*	(0.253)	(0.345)
					hotels				
Q(12)	5.481	19.671	18.6216	16.742	2.248	4.224	3.159	20.222	15.213
	(0.165)	(0.074)*	(0.098)*	(0.160)	(0.972)	(0.836)	(0.076)*	(0.003)***	(0.230)
ARCH(4)	0.279	3.393	6.187	4.124	5.165	9.770	0.694	1.703	6.361
	(0.597)	(0.494)	(0.186)	(0.390)	(0.271)	(0.044)**	(0.952)	(0.790)	(0.174)
ARCH(8)	3.175	9.261	13.555	13.82	15.875	14.787	9.002	2.793	8.793
	(0.529)	(0.321)	(0.094)*	(0.087)*	(0.044)**	(0.063)*	(0.342)	(0.947)	(0.360)
JB	7.957	1.218	1.295	2.632	1.690	0.259	8.464	2.042	1.806
	(0.438)	(0.544)	(0.523)	(0.268)	(0.430)	(0.878)	(0.015)**	(0.360)	(0.405)
RESET	0.317	1.548	1.536	0.332	1.932	0.789	0.510	0.946	1.113
	(0.813)	(0.203)	(0.207)	(0.803)	(0.107)	(0.534)	(0.602)	(0.419)	(0.345)

Notes: Q(12) is the Lagrange Multiplier test statistic for up to twelfth order serial correlation in the residuals. ARCH(4) and ARCH(8) are Lagrange Multiplier test statistics for autoregressive conditional heteroskedasticity in the residuals of order four and eight, respectively. JB is the test statistic of the Jarque-Bera normality test. RESET is the Ramsey (1969) test for remaining nonlinearity. In parenthesis are p-values. *, ** and *** denote statistical stignificance at the 10%, 5% and 1% signifcance levels respectively.

Table 4.A. Haf-Lives

Shock (%)	10	20	30	40	50	60	*hl* lin
			bread				
BE	47	33	25	22	21	20	12
DK	48	33	26	23	21	20	14
DE	28	26	25	25	25	25	20
FR	27	26	25	25	25	25	21
IT	20	13	11	10	10	10	6
NL	19	19	18	18	18	18	17
PT	37	32	30	28	27	27	22
SP	80	58	43	29	22	18	9
UK	12	8	7	7	6	6	4
			meat				
BE	27	20	17	16	15	15	12
DK	27	26	25	25	24	24	22
DE	26	25	25	24	24	24	22
FR	27	26	25	25	24	24	24
IT	19	19	18	18	18	18	17
NL	25	25	24	24	24	24	20
PT	9	8	7	7	7	7	5
SP	49	28	17	13	12	11	5
UK	10	9	9	9	9	9	7
			dairy				
BE	38	21	16	14	13	13	8
DK	34	23	19	17	16	15	12
DE	40	26	20	17	16	15	11
FR	27	26	25	25	24	24	21
IT	26	14	10	9	8	8	4
NL	22	20	19	19	19	19	19
PT	26	25	24	24	24	24	24
SP	31	28	27	26	25	25	33
UK	20	19	18	18	18	18	17
			fruit				
BE	22	19	17	16	15	15	9
DK	9	9	9	9	9	9	8
DE	24	22	21	20	20	20	15
FR	24	18	14	13	12	12	7
IT	13	8	7	6	5	5	4
NL	27	22	19	18	17	17	15
PT	9	8	7	7	7	7	4
SP	14	12	12	11	11	11	9
UK	16	13	12	11	10	10	8

continued next page...

...table 4.A. continued

Shock (%)	10	20	30	40	50	60	*hl* lin
				tobac			
BE	26	25	25	24	24	24	20
DK	26	25	25	24	24	24	20
DE	14	7	5	5	4	4	3
FR	30	27	26	26	25	25	24
IT	7	5	4	4	4	4	2
NL	13	10	9	9	8	8	7
PT	23	16	10	8	7	7	4
SP	16	16	15	15	15	15	14
UK	17	11	9	8	8	8	6
				alco			
BE	27	26	25	25	24	24	26
DK	15	14	13	13	13	12	11
DE	44	31	24	22	20	20	15
FR	25	24	24	24	24	24	24
IT	30	28	26	26	25	25	23
NL	27	26	25	25	24	24	20
PT	98	77	65	58	53	50	33
SP	48	44	42	40	39	38	34
UK	18	16	15	14	14	14	12
				cloth			
BE	60	48	41	36	33	32	26
DK	29	27	26	26	25	25	24
DE	47	34	28	25	24	23	18
FR	44	41	40	39	38	37	38
IT	61	45	29	21	17	16	8
NL	11	11	11	11	11	11	10
PT	30	28	27	26	25	25	34
SP	42	40	39	38	37	37	34
UK	11	11	11	11	11	11	10
				foot			
BE	78	60	49	43	38	35	16
DK	61	44	25	18	15	14	6
DE	49	36	29	26	24	23	18
FR	43	40	39	38	38	37	39
IT	58	43	31	26	23	22	13
NL	11	10	10	10	10	10	9
PT	30	28	27	26	25	25	34
SP	41	39	38	37	37	37	34
UK	23	15	12	10	10	10	7

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...table 4.A. continued

Shock (%)	10	20	30	40	50	60	*hl* lin
				fuel			
BE	16	15	15	15	15	15	14
DK	80	52	21	16	15	14	4
DE	27	26	25	25	24	24	24
FR	27	26	25	25	25	24	24
IT	44	25	16	12	10	10	5
NL	22	20	19	19	19	18	18
PT	22	14	10	8	8	7	5
SP	22	12	8	7	7	7	4
UK	19	17	16	16	15	15	14
				furniture			
BE	70	54	43	35	30	28	18
DK	63	51	42	37	34	32	22
DE	37	28	24	23	21	21	18
FR	48	44	42	40	39	39	33
IT	45	26	13	8	6	6	2
NL	61	46	33	27	24	22	13
PT	59	53	42	34	30	27	19
SP	66	53	44	38	34	32	20
UK	55	26	16	14	13	13	4
				dom			
BE	47	43	41	40	39	38	31
DK	44	41	40	38	38	37	29
DE	41	40	38	38	37	37	33
FR	42	40	39	38	37	37	28
IT	24	14	8	7	6	5	3
NL	23	21	20	19	19	19	19
PT	58	41	25	17	13	11	5
SP	45	22	12	8	7	6	3
UK	22	10	8	7	7	7	3
				vehicles			
BE	48	32	24	20	19	18	11
DK	68	54	44	38	34	32	23
DE	49	40	34	31	29	28	20
FR	48	33	24	20	19	18	11
IT	18	13	11	10	10	10	8
NL	48	39	34	31	29	28	21
PT	48	44	41	40	39	38	36
SP	51	33	20	16	14	12	7
UK	20	19	19	19	18	18	19

continued next page...

...table 4.A. continued

Shock (%)	10	20	30	40	50	60	*hl* lin
				comm			
BE	21	18	17	16	16	16	13
DK	39	38	37	37	36	36	31
DE	21	20	19	19	19	19	18
FR	24	20	19	18	17	17	14
IT	11	10	10	9	9	9	9
NL	38	27	22	20	18	18	14
PT	13	13	12	12	12	12	12
SP	54	35	22	16	14	12	8
UK	14	13	13	12	12	12	12
				sound			
BE	25	18	16	15	14	14	9
DK	30	27	26	26	25	25	25
DE	45	29	22	19	18	17	11
FR	27	23	22	21	20	20	17
IT	24	14	8	6	5	4	2
NL	26	13	9	8	8	8	3
SP	23	17	14	13	12	12	10
UK	9	6	5	5	5	5	3
				books			
BE	41	39	38	37	37	37	33
DK	46	34	28	25	24	23	15
DE	42	27	21	19	18	17	12
FR	38	25	20	18	17	17	11
IT	21	13	9	8	7	7	4
NL	32	22	18	17	16	16	11
PT	31	20	14	11	10	9	5
SP	43	41	40	39	38	38	31
UK	19	19	18	18	18	18	19
				hotels			
BE	42	40	39	38	37	37	7
DK	11	11	11	11	11	11	5
DE	15	8	7	7	7	6	3
FR	34	20	15	14	13	12	7
IT	18	10	9	9	8	8	3
NL	14	9	8	7	7	7	3
PT	39	38	37	37	37	36	31
SP	60	44	26	21	20	19	8
UK	16	13	13	12	12	12	7

Notes: This table shows the estimated half-lives of deviations from the LOOP for six different sizes of percentage shock: 10, 20, 30, 40, 50 and 60. The half-lives were calculated conditional on average initial history using the generalized impulse response functions procedure developed by Koop et al. (1996). *hl* lin is the half-life of the SETAR model in the outer regime, calculated as $\ln 0.5/\ln\rho$.

Table 4.B. Average Haf-Lives per Country

Shock (%)	10	20	30	40	50	60	*hl* lin
BE	40	32	28	26	24	24	17
DK	41	32	26	24	23	22	17
DE	34	27	23	22	21	20	16
FR	33	29	27	26	25	25	22
IT	27	19	14	12	11	10	7
NL	26	21	19	18	17	17	14
PT	35	30	25	23	22	21	18
SP	43	33	26	23	22	21	16
UK	19	14	13	12	12	12	9

Table 4.C. Average Haf-Lives per Sector

Shock (%)	10	20	30	40	50	60	*hl* lin
bread	35	28	23	21	19	19	14
meat	24	21	19	18	17	17	15
dairy	29	22	20	19	18	18	17
fruit	18	15	13	12	12	12	9
tobac	19	16	14	14	13	13	11
alco	37	32	29	27	26	26	22
cloth	37	32	28	26	25	24	23
foot	44	35	29	26	24	24	19
fuel	31	23	17	16	15	15	13
furniture	56	42	33	28	26	24	16
dom	38	30	26	24	23	22	17
vehicles	44	34	28	25	23	22	17
comm	26	22	19	18	17	17	14
sound	26	18	15	14	13	13	10
books	35	27	23	21	21	20	16
hotels	28	21	18	17	17	16	8

Notes: Tables 4.B. and 4.C. show the average half-lives per contry and per sector respectively. The calculations are based on Table 4.A.

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