The Law of One Price: Nonlinearities in Sectoral Real Exchange Rate Dynamics*

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Abstract

Using Self-Exciting Threshold Autoregressive Models (SETAR), this paper explores the validity of the Law of One Price (LOOP) for nineteen sectors in ten European countries. We find strong evidence of nonlinear mean reversion in deviations from the LOOP. We highlight the importance of modelling the real exchange rate in a nonlinear fashion in an attempt to solve the PPP Puzzle. Using the US dollar as a reference currency, half-life estimates range from six to sixteen months (country averages), which are significantly lower than the 'consensus estimates' of three to five years. The results also show that transaction costs differ enormously across sectors and countries.

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

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1 Introduction

The law of one price (LOOP) states that similar goods should have the same price across countries if prices are expressed in a common currency.

This argument implies that there is a frictionless goods arbitrage. It is usually seen, however, that homogeneous goods are sold at different prices in different countries. This evidence contradicts the idea of arbitrage postulated in the LOOP.

One reason why prices of similar commodities may not be the same across different countries is the existence of transaction costs such as transport costs, tariffs and nontariff barriers.

Several theoretical studies account for the importance of transaction costs in modelling deviations from the LOOP (see Dumas, 1992; Sercu *et.al.*, 1995; O'Connell, 1998 and Obstfeld and Rogoff, 2000). These studies explain that due to frictions in international trade, deviations from the LOOP should contain significant nonlinearities. The idea is that deviations from the LOOP will be non-stationary when they are smaller than transaction costs since they will not be worth arbitraging.

Based on these theoretical contributions, a number of empirical studies investigate the nonlinear nature of the deviation from the LOOP (Obstfeld and A.M. Taylor, 1997; A.M. Taylor, 2001; Sarno, M.P. Taylor and Chowdhury, 2002) 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 the deviations from the LOOP could exhibit unit root behaviour. Outside the band, in the presence of profitable arbitrage opportunities, the process becomes mean reverting.

These studies provide evidence of the presence of nonlinearities in deviations from the LOOP. However, their validity is sometimes criticized because they are based on few commodities or currencies. In order to overcome this limitation, in our paper we use the highly disaggregated database previously analysed by Imbs *et.al.* (2003 and 2005). The main difference between the work of Imbs *et.al.* (2003) and our paper is that the former focuses on the determintants of international trade segmentation. Our emphasis is different. Our starting point is that the low power of the unit root tests gives room to the study of the deviations from the LOOP in a nonlinear fashion. We test the validity of modelling the deviations from the LOOP allowing for nonlinearities and estimate a TAR model for each sectoral real exchange rate.

More precisely, we investigate the presence of threshold-type nonlinearities in deviations from the LOOP using real dollar sectoral exchange rates *vis-à-vis* ten major European currencies for nineteen sectors over the period 1981-1995. A total of one hundred and eighty-seven sectoral real exchange rates are analysed[1]. Nonlinearities are modelled using a Self-Exciting Threshold Autoregressive Model (SETAR).

Our results suggest that the SETAR model characterises well the deviations from the LOOP for a broad range of currencies and 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 analysed. In addition, there is also a country effect: some countries exhibit relatively low thresholds for a given sector.

In order to check that our model performs well independently of the reference currency chosen, the same estimations are carried out using the UK pound as the reference currency. The results are very satisfactory. We find strong evidence of nonlinear mean reversion and, consistent with economic intuition, transaction costs are significantly reduced when using the UK pound as the reference currency. Another result to highlight is that the country averages half-lives implied by the SETAR model are generally lower using the UK pound as the reference currency.

There is a certain consensus in the literature that exchange rates may converge to parity in the long run. However, the speed at which this happens seems to be very slow. A usual measure of the speed of mean reversion is the half-life, which is the time it takes for the effects of 50% of a shock to die out. Rogoff (1996) points out that the 'consensus estimates' of the half-lives are three to five years. Since the short-run volatility in real exchange rates is mainly due to monetary or financial shocks, these shocks have real effects on the economy because of the presence of nominal rigidities. However, the half-lives from three to five years are too large to be explained by nominal rigidities. Hence, Rogoff (1996) calls this result the 'Purchasing Power Parity Puzzle'.

The half-life estimates obtained in our study are significantly lower than the 'consensus estimates'. Hence, our results confirm the importance of deviating from a linear specification when modelling deviations from the LOOP (see M.P. Taylor, Peel and Sarno, 2001 and Sarno, M.P. Taylor and Chowdhury, 2002).

The rest of the paper is organised as follows. Section 2 presents the motivation for the modelisation of the exchange rate in a nonlinear fashion. Section 3 outlines the Self-Exciting Threshold Autoregressive (SETAR) model to be estimated and the econometric technique we employ. Section 4 presents the Hansen test for nonlinearity. Section 5 describes the data to be used. Preliminary unit root tests results are shown in section 6. Section 7 contains the estimation results. Robustness checks are carried

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

out in section 8. Finally, section 9 presents the conclusion.

2 Nonlinear Dynamics in Exchange Rates: 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 the 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[2], 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 be sold at a higher price in another country.

Early studies on the LOOP (Isard, 1977; Richardson, 1978 and Giovannini, 1988) do not find evidence of mean reversion and also suggest that the deviations from the LOOP are very volatile and highly correlated with exchange rate movements.

One of the reasons why the LOOP may not hold is due to the presence of transportation costs, tariffs and nontariff barriers. These can create a wedge between prices of different countries. An estimate of international transportation costs can be obtained by comparing the FOB value of world exports, which exclude shipping costs and insurance, with the CIF value of world imports, which include shipping and insurance costs. Estimates of the International Monetary Fund suggest that the difference is around 10 per cent.

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. Government of many countries often intervene in trade across borders using nontariff barriers in a way that they do not use within borders. Knetter (1994) argues that nontariff barriers are important empirically to explain deviations from PPP.

[2] 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).

Another factor that can 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 affect the price of the goods.

The main point is that frictions to trade can imply the presence of nonlinearities in international goods arbitrage. This insight dates from Heckscher (1916), who pointed out that transaction costs should create some scope for deviations from the LOOP. More recently, a number of authors have developed theoretical models that account for the presence of nonlinear exchange rate dynamics when there are transaction costs in international arbitrage (see Dumas, 1992; Sercu *et.al.*, 1995; O'Connell, 1998 and Obstfeld and Rogoff, 2000). 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 for the real exchange rate within which the marginal costs of arbitrage exceed the marginal benefit. Hence, within this band there is a no-trade zone.

The estimated transaction costs band may be wider than the one implied by transport costs and barriers to trade. This point was considered in Dumas (1992). He studies a two-country general equilibrium model in the framework of an homogenous investment-consumption good. He 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 shows mean reverting properties.

O'Conell and Wei (2002) extend the analysis using a broader interpretation of market frictions in which they operate 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 the deviations from the LOOP are generated. The idea is that arbitrage will be strong when it is profitable enough to outweight 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.

Some recent papers that study the deviations from the LOOP in a nonlinear framework are Obstfeld and A.M. Taylor (1997), A.M. Taylor (2001), Sarno, M.P. Taylor and Chowdhury (2002) and Imbs *et.al.* (2003). These studies analyse the presence of a nonlinear adjustment in exchange rates dynamics using a TAR model (Tong, 1990). The TAR models allow for the presence of a 'band of inaction' within which no trade takes place. Hence, inside the band, when no trade takes place, the deviations from the LOOP could exhibit unit root behaviour. Outside the band, in the presence of profitable arbitrage opportunities, the process becomes mean reverting.

Obstfeld and A.M. 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 considerably variation in their estimates across sectors and countries.

A.M. 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.

Sarno, M.P. Taylor and Chowdhury (2002) 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.

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

In summary, all 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.

3 Econometric Method: Model and Estimation

The theoretical models described in the previous section motivate the study of the deviations from the LOOP using a threshold-type model. In this section we will describe the model to be estimated. The idea is that transaction costs 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 the deviations from the LOOP are persistent. Once above or below this band, arbitrage takes place and the deviations from the LOOP become mean reverting.

Let us define 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 Threshold Autoregressive Model (TAR) may be written as

$$
\begin{aligned}
q^i_{jt} &= \alpha q^i_{jt-1} + \varepsilon^i_{jt} \text{ if } \left|q^i_{jt-d}\right| < \kappa && (2)\\
q^i_{jt} &= \kappa(1-\rho) + \rho q^i_{jt-1} + \varepsilon^i_{jt} \text{ if } q^i_{jt-d} \geq \kappa && (3)\\
q^i_{jt} &= -\kappa(1-\rho) + \rho q^i_{jt-1} + \varepsilon^i_{jt} \text{ if } q^i_{jt-d} \leq -\kappa && (4)\\
\epsilon^i_{jt} &\sim N(0,\sigma^2) && (5)
\end{aligned}
$$

where κ is the threshold parameter, q^i_{jt-d} is the threshold variable for sector i and country j, and d denotes an integer chosen from the set $\Psi \in \left[1, \overline{d}\right]$. The error term is assumed to be independently and identically distributed (iid) Gaussian.

The model described is one of a family of TAR (p,q,d), where p is the autoregressive parameter, q represents the number of thresholds and d is the delay parameter. The latter captures the idea that it takes time for economic agents to react to deviations from the LOOP. The simple model we proposed is a TAR $(1,2,d)$. 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 $(1,2,d)$.

This model implies that within the band deviations from the LOOP follow an autoregressive process with slope coefficient α. Once at or beyond the threshold, $\left|q^i_{jt-d}\right| \geq \kappa$, the deviations switch to a different autoregressive process with slope coefficient ρ.

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 restricted the value of α to equal unity[3] so inside the band, when $\alpha = 1$, the process follows a random walk. When $\left|q^i_{jt-d}\right| \geq \kappa$ the process becomes mean reverting as long as $\rho < 1$. This specification assumes that reversion is towards the edge of the band.

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

[3] Obstfeld and A.M. Taylor (1997) estimate a TAR model imposing this restriction and so do Imbs *et.al.* (2003).

$$
\begin{aligned}
q^i_{jt} &= \left[\kappa\left(1-\rho\right)+\rho q^i_{jt-1}\right]1\left(q^i_{jt-d}\geq\kappa\right)+q^i_{jt-1}1\left(\left|q^i_{jt-d}\right|<\kappa\right)\\
&\quad+\left[-\kappa(1-\rho)+\rho q^i_{jt-1}\right]1\left(q^i_{jt-d}\leq-\kappa\right)+\epsilon^i_{jt} \qquad (6)
\end{aligned}
$$

The model in (6) is assumed to be symmetric. Thus, deviations from the LOOP outside the threshold band adjust in the same way regardless of whether prices are higher in the US or in another country[4].

For exposition purposes let us re-write equation (6) as

$$
\Delta q^i_{jt}=\left[(\rho-1)\left(q^i_{jt-1}-\kappa\right)\right]1\left(q^i_{jt-d}\geq\kappa\right)+(\rho-1)\left(q^i_{jt-1}+\kappa\right)1\left(q^i_{jt-d}\leq-\kappa\right) \qquad (7)
$$

Hence,

$$
\Delta q^i_{jt}=B^i_{jt}(\kappa,d)'\Gamma+\epsilon^i_{jt} \qquad (8)
$$

where $B^i_{jt}(\kappa,d)'$ is a (1×2) row vector that describes the behaviour of Δq^i_{jt} in the outer regime[5] and Γ is a (2×1) vector containing the autoregressive parameters to be estimated. This vector can be represented as

$$
B^i_{jt}(\kappa,d)'=\left[\begin{array}{cc} X'1\left(q^i_{jt-d}\geq\kappa\right) & Y'1\left(q^i_{jt-d}\leq-\kappa\right)\end{array}\right] \qquad (9)
$$

where

$$
\begin{aligned}
X' &= \left[q^i_{jt-1}-\kappa\right]\\
Y' &= \left[q^i_{jt-1}+\kappa\right]
\end{aligned}
$$

and

$$
\Gamma'=\left[\begin{array}{cc}\rho-1 & \rho-1\end{array}\right] \qquad (10)
$$

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

[4] There is no explanation from economic theory stating that prices would adjust differently if they are higher in one country or another.

[5] In the model in (6) the autoregressive parameter was restricted to equal unity inside the threshold band. Hence, when considering the model in (7) it follows that withind the band $\Delta q^i_{jt}=0$ and consequently this term does not appear in our estimation. It would be possible to estimate the model without assuming this restriction. However, the restriction appears to be valid since it is justified by economic theory.

$$\widehat{\Gamma}(\kappa,d)=\left(\sum_{t=1}^{T}B_{jt}^{i}(\kappa,d)B_{jt}^{i}(\kappa,d)'\right)^{-1}\left(\sum_{t=1}^{T}B_{jt}^{i}(\kappa,d)\Delta q_{jt}^{i}\right) \tag{11}$$

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

$$\widehat{\sigma}^{2}(\kappa,d)=\frac{1}{T}\sum_{t=1}^{T}\widehat{\epsilon}_{jt}^{i}(\kappa,d)^{2} \tag{12}$$

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, d and ρ via a grid search over κ and d. The model is estimated by sequential least squares for values of d from 1 to 6. The values of κ and d that minimise the sum of squared residuals are chosen. This can be written as

$$\left(\widehat{\kappa},\widehat{d}\right)=\underset{\kappa\in\Theta,\ d\in\Psi}{\arg\min}\,\widehat{\sigma}^{2}(\kappa,d) \tag{13}$$

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 $\widehat{\epsilon}_{jt}^{i}\left(\widehat{\kappa},\widehat{d}\right)=\Delta q_{jt}^{i}-B_{jt}^{i}(\widehat{\kappa},\widehat{d})'\widehat{\Gamma}\left(\widehat{\kappa},\widehat{d}\right)$ and residual variance $\widehat{\sigma}^{2}\left(\widehat{\kappa},\widehat{d}\right)=\frac{1}{T}\sum_{t=1}^{T}\widehat{\epsilon}_{jt}^{i}\left(\widehat{\kappa},\widehat{d}\right)^{2}$.

4 Testing for Nonlinearity

Before analysing the results from the estimation of the SETAR model, it is important to test whether the nonlinear specification is superior to a linear model. In other words, we need to test if we can reject the null hypothesis of linearity ($\rho=1$) in favour of the nonlinear model.

As Hansen (1997) pointed out, testing this hypothesis is not that straightforward. A statistical problem is present because conventional tests of the null of a linear autoregressive model against the SETAR have asymptotic nonstandard 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.

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

$$F_T(\kappa, d) = T\left(\frac{\widetilde{\sigma}^2 - \widehat{\sigma}^2(\kappa, d)}{\widehat{\sigma}^2(\kappa, d)}\right) \tag{14}$$

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 restricted and unrestricted estimates of the residual variance. Hence, $\widetilde{\sigma}^2$ is equal to $\frac{1}{T}$ times the sum of squared residuals resulting from the estimation of (6) with the restriction $\rho = 1$ and $\widehat{\sigma}^2(\kappa, d)$ is defined in (12).

Since κ and d are not identified under the null hypothesis, the distribution of $F_T(\kappa, d)$ is not χ^2. Hansen (1997) shows that the asymptotic distribution of $F_T(\kappa, d)$ may be approximated using a 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 $q_{jt-1}^{i}, t = 1, ..., T$, estimate the restricted and unrestricted model and obtain the residual variances $\widetilde{\sigma}^{*2}$ and $\widehat{\sigma}^{*2}(\kappa, d)$. With these residual variances, it is possible to calculate the following F-statistic

$$F_T^*(\kappa, d) = T\left(\frac{\widetilde{\sigma}^{*2} - \widehat{\sigma}^{*2}(\kappa, d)}{\widehat{\sigma}^{*2}(\kappa, d)}\right) \tag{15}$$

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

The data on sectoral exchange rates was originally obtained from Eurostat and is the one used by Imbs *et.al.* (2003). The data contains monthly observations on two-digit non-harmonised prices (CPI) for nineteen goods categories and bilateral nominal exchange rates against the US dollar. The period analysed is 1981:01 to 1995:12. The countries covered are Belgium, Denmark, Germany, Greece, France, Italy, Netherlands, Portugal, Spain, UK and the US as a reference country[6]. The sectors analysed are: bread and cereals (bread), meat (meat), dairy products (dairy), fruits (fruits), tobacco (tobac), alcoholic and non alcoholic drinks (alco), clothing (cloth), footwear (foot), rents (rents), fuels and energy (fuel), furniture (furniture),

[6] The database contains information on Finland as well. However, since there are many missing values it was not considered for this study.

domestic appliances (dom), vehicles (vehicles), public transport (pubtrans), communication (comm), sound and photographic equipment (sound), leisure (leisure), books (books) and hotels (hotels).

Dollar sectoral real exchange rates q^i_{jt} in logarithmic form are calculated *vis-à-vis* the ten European currencies of the countries mentioned before in the way defined in equation (1). In all cases, the demeaned sectoral real exchange rate is used for the estimation of the LOOP.

6 Unit Root Tests

The hypothesis that deviations from the LOOP are nonstationary was tested by applying different unit root tests (not reported here but available from the authors upon request). For each of the sectoral exchange rates the null hypothesis of unit root was generally not rejected at conventional significance levels.

The Dickey Fuller test, for example, is the t test for $\alpha = 1$ of the following AR(1) regression

$$q^i_{jt} = \alpha q^i_{jt-1} + \varepsilon^i_{jt} \tag{16}$$

As M.P. Taylor *et.al.* (2001) pointed out, if the exchange rate dynamics displays a 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, making it more difficult to reject the unit root null hypothesis.

Table 1 shows a simulation of the power of the Dickey Fuller test for p=0.05 significance level assuming that the model displays a nonlinear adjustment. The power of the test represents the number of times the test rejects the unit root null hypothesis given that the process is stationary. The results illustrate the potential problem of using an AR(1) stationary test to test for unit root in the context of the LOOP.

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 to conclude that the exchange rate follows a nonstationary process when in fact may be nonlinearly mean reverting.

7 Estimation Results

7.1 Linearity Tests

The bootstrapped p-values calculated using the Hansen test are shown in Table 2. The null hypothesis of linearity is rejected in 111 out of 187 cases at a 5% level. At a 10% level the null hypothesis of linearity is rejected in 125 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.

In sectors such as rents and leisure, which are highly non-tradable, we fail to reject the linearity hypothesis for most countries. Given its non-tradability nature, it seems reasonable not to find evidence of mean reversion. These results are in line with those described in Imbs *et.al.* (2003).

In sectors that involve a high degree of differentiation and high shipping costs such as sound, fuel and furniture we find evidence of nonlinearities in the majority of countries. In the case of low cost food sectors, evidence of nonlinearities is strong for fruits, which is a highly homogeneous good, and significant for dairy. Strong evidence of nonlinerities is found in the meat sector.

Nonlinearities appear to be strong in tobacco and communication sectors and are found for a majority of countries in clothes and domestic appliances.

Nonlinearities seem weak in sectors that at first glance appear to be highly tradable such as footwear and alcoholic and nonalcoholic drinks. In this case, the failure to account for nonlinearities could be due to the fact that these goods are not homogeneous and the low substitutability can prevent arbitrage.

Mixed evidence of nonlinearities is present in sectors such as bread, vehicles and books. In the case of vehicles, international arbitrage could be difficult due to different national standards (i.e. right-hand-side cars in the UK). In the case of books, the barriers imposed by the language in which books are written could prevent arbitrage from taking place.

One interesting result is to find 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.

Even though the evidence of nonlinearities in the public transport sector may seem noisy at first glance, we could explain this result as follows. Although it is a nontradable sector, its main input is oil, which is a highly tradable good. Apart from this, it is important to take into account that prices in the transport sector may be affected by country specific policies. Hence, the behaviour of prices may follow a different pattern with respect to other sectors.

7.2 SETAR Estimation

Table 2 shows the results for the estimated SETAR model. 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 analysed. Some sectors that involve high shipping costs and that are less homogeneous are clearly characterised by higher threshold bands. In addition, a country effect seems to be present. For a given sector, some countries exhibit relatively lower thresholds.

In this section a greater emphasis will be given to the behaviour 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 The half-lives

The half-life is a measure of the speed of mean reversion. Specifically, it is the time it takes for the effects of 50% of a shock to dissipate. Using country averages, the results show that the half-life (hl=ln0.5/lnρ) of deviations are extraordinarily smaller for the case of the SETAR model than the linear AR(1) model. The average half-life using the linear model is 104 months with country averages ranging from 20 to 230 months. In contrast, the average half-life based on the SETAR model is 12 months with country average half-lives between 6 and 16 months.

Considering those cases in which nonlinearities are detected, short half-lives are observed in the Greek fruit market (hl=3 months), the Spanish tobacco sector (hl=2.6 months) and the Italian fuel sector (hl=3 months).

The SETAR model estimation also indicates that the half-lives are lower than the ‘consensus’ estimates, which suggest a half-life from three to five years. Hence, there is no puzzle in a Rogoff (1997) sense. These results convey the importance of modelling the deviations from the LOOP in a nonlinear framework.

7.2.2 Transaction costs

Transaction costs differ enormously across sectors and countries. Relatively high transaction costs are observed for vehicles and furniture. Considering the countries for which nonlinearities are detected, the estimated $\widehat{\kappa}$ rage from 15.8% to 24.6% for vehicles and from 9.9% to 21.7% for furniture. It seems reasonable to find high threshold bands for these sectors given their high shipping costs and their high degree of differentiation. In addition, in the case of vehicles there are barriers to arbitrage caused by the difference in international standards.

For the fruit market, the US and European countries examined appear to be highly integrated. Except for the UK and Spain, where $\widehat{\kappa}$ is 18.1% and 15% respectively, in the other countries it ranges from 1.9% to 5.2%.

The estimated threshold parameters are relatively high for some countries in tobacco, clothes and footwear sectors. When this happens, we are unable to reject the linearity hypothesis.

In the case of tobacco, we fail to find evidence of nonlinearities in France and Greece. The low thresholds in Germany and the UK imply that the tobacco markets of these countries are integrated with the American one.

In the case of clothes, the evidence of nonlinearities is mixed. In Denmark, Germany, Greece, Italy, Netherlands, Spain and the UK, nonlinearities are detected. The behaviour of the transaction costs band differs across these countries. The lowest thresholds are found in Netherlands and the UK, where the estimated $\widehat{\kappa}$ is 6.1% and 7% respectively. High threshold bands are observed in Germany, where $\widehat{\kappa}$ is 24.5%.

In the footwear sector, evidence of nonlinearities is found in France, Netherlands, Italy and the UK. Among these countries, the highest transaction costs correspond to Italy (30.4%) and the lowest to the Netherlands (3.2%).

Overall, the estimation suggests 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 fruits, where thresholds are very low. The same happens for fuel, furniture, vehicles and sound, where thresholds are relatively high.

A less mentioned result in the literature is the country effect. By and large, there are 'low thresholds countries' composed by Belgium, Germany, Denmark, France, Netherlands and the UK and 'high threshold countries', which are Spain, Italy, Greece and Portugal. Average transaction costs estimates for the former group range from 8.7% (Netherlands) to 16.7% (Denmark). For the latter group, average threshold estimates range from 20.2% (Greece) to 26.2% (Spain)[7].

In comparison to the work of Obstfeld and A.M. Taylor (1997) our estimated threshold bands are slightly higher, ranging from 8.7% to 26.2.% (country averages). The authors previously mentioned find location average estimated thresholds ranging

[7] Specifically, average transaction costs are 16.5% for Belgium, 13.6% for Germany, 16.7% for Denmark, 12.7% for France, 8.7% for Netherlands, 10% for the UK, 26.2% for Spain, 21.1% for Italy, 20.2% for Greece and 24.5% for Portugal.

from 7% to 10%. However, considering only European countries their results show that the threshold bands are between 9% and 19%, which are close to our estimates.

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(1) model.

7.2.3 The Delay Parameter

The estimation of the SETAR model suggests that the speed at which agents react to deviations from the LOOP is very heterogeneous across goods and across countries for a given good. In only 57 out of the 187 cases the results show that the delay parameter is equal to 1. Most of the estimated values of d fall in the 2-3 interval. Overall, the average estimate of the delay parameter is 3.

In the fruits and communication sectors, for example, agents appear to react to deviations from the LOOP very rapidly. The average delay parameter is 2 for the former and 1 for the latter sector. In contrast, in the fuel, furniture and domestic appliances sectors, agents do not exploit the arbitrage opportunities quickly and the average delay estimate is 4. This seems a reasonable result taking into account the high degree of differentiation of these sectors.

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 turned 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 Robustness of Results

We tested the robustness of the results to the use of the UK pound as the reference currency. The reason for doing this is that we would like to make sure our conclusions do not depend on using the US dollar as a reference currency. The estimations are included in an appendix at the end of the paper.

The results confirm the robustness of our baseline estimation. When using the UK pound as the reference currency, the evidence of nonlinearities is very strong. Hence, the SETAR model characterises very well the deviations from the LOOP independently of the country of reference[8].

[8] The results are also robust to the use of the Deutsche Mark as a reference currency.

In fact, with the UK pound as the reference currency, the null hypothesis of linearity is rejected in 124 out of 187 cases at a 5% level. At a 10% level the null hypothesis of linearity is rejected in 140 cases. This means that there is evidence of nonlinear mean reversion in deviations from the LOOP in 75% of the sectoral real exchange rates analysed. These results are slightly more satisfactory than in the case in which the US dollar is the referece currency (in the latter specification nonlinearities were found in 125 cases at 10% level).

One important result to highlight is that when using the UK pound as the reference currency the threshold bands are significantly reduced. Average transaction costs range from 7.4% (Italy) to 16.8% (Portugal)[9]. This is a reasonable result which can be explained as follows. From an empirical point of view, the result is in line with the work of Obstfeld and A.M. Taylor (1997) and Imbs et.al. (2003) which point out the significant role of transport costs (proxied as geographic distance) to explain transaction costs. The lower threshold bands in the UK pound specification are also due to the fact that markets are more integrated between European countries than between European countries and the US. As it was previously mentioned, another source of failure of goods market arbitrage is the presence of nontraded component in goods that appear to be highy tradable. In this case, it is clear that labour costs and taxes have less variation across European countries than with relation to the US.

Another result to point out is that the half-lives implied by the linear model are lower using the UK pound as a reference currency. Similarly, the half-lives implied by the SETAR model are generally higher using the US dollar as the reference currency.

At a sectoral level, the main points to mention are the following. Evidence of nonlinearities is very weak for nontradable sectors such as rents and leisure. In contrast to the baseline case, we failed to reject the linearity hypothesis in a majority of countries for the communication sector. Mixed evidence of nonlinearities is found in the clothes and footwear sectors. In the case of food sectors (bread, meat, dairy and fruits), the evidence of nonlinearities is strong. The same happens with sectors that involve high shipping costs such as fuel, furniture, sound and vehicles.

As a further robustness check, the SETAR models using the UK pound as a reference currency were estimated restricting d to equal unity. In line with the results of the baseline specification, it turned out that the estimated parameters do not change considerably from one specification to the other.

[9] Specifically, average transaction costs are 12.2% for Belgium, 9.6% for Germany, 12.8% for Denmark, 11.1% for Greece, 10.3% for France, 7.4% for Italy, 7.9% for Netherlands, 16.8% for Portugal and 14% for Spain.

9 Conclusions

This study shows that when modelling the deviations from the LOOP in a nonlinear fashion we find supportive evidence of mean reversion.

There is great heterogeneity in transaction costs in different sectors and countries. Using the US dollar as the reference currency, the estimated threshold bands range from 8.7% to 26.2% (country averages).

The estimated half-lives are substantially reduced when modelling the deviations from the LOOP using a SETAR model in comparison to a linear AR(1) model. The estimated half-lives implied by the nonlinear model range from 6 to 16 months (country averages). In contrast, 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.

The time it takes for economic agents to react to deviations from the LOOP varies across sectors and countries. The average value of the delay parameter is 3. This may suggest that the delay parameter should be estimated and not restricted to be equal to 1 as has been done in other empirical work. However, the results are very robust and the estimated parameters do not change considerably when d is restricted to equal unity.

As a robustness check the SETAR model was estimated using the UK pound as the reference currency. The results of this estimation confirmed that the SETAR model characterises very well the deviations from the LOOP independently of the country of reference. Transaction costs and half-lives were generally lower when using the UK pound as a reference currency.

The agenda for future research is large. However, there are two points that are worth mentioning. This work shows the importance of sectoral heterogeneity. In this way it contributes to the findings of Imbs *et.al.* (2005) who suggested that the slow speeds of adjustment could be due to an aggregation bias arising from the heterogeneous speed of adjustment of disaggregated relative prices. The authors reach this conclusion using linear panel data estimators. It would be interesting to extend the analysis using nonlinear panel data. In his way we could allow both for the presence of sectoral heterogeneity and nonlinear adjustment.

In this work we are assuming that the deviations from the LOOP converge to a constant real exchange rate, which is assumed to be the mean. However, it is possible that this equilibrium value of the real exchange rate changes over time. The extension of the analysis allowing for the possibility of a non-constant equilibrium level of the real exchange rate is another area for future research.

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Table 1. Power of the Dickey Fuller Test at 5% significance level

	BE	**DK**	**GE**	**GR**	**FR**	**IT**	**NE**	**PT**	**SP**	**UK**
bread	7.34	8.61	7.60	8.89	9.50	16.26	7.22	56.25	27.43	15.78
meat	11.95	24.14	6.51	11.70	7.26	8.89	7.42	48.42	54.10	24.22
dairy	7.45	48.17	8.92	17.95	8.42	13.25	8.04	10.04	6.98	11.08
fruit	40.54	25.72	41.56	34.20	39.64	11.72	34.57	26.13	38.50	20.41
tobac	13.82	43.57	19.23	37.53	26.50	-	20.43	43.42	43.42	13.52
alco	9.65	7.42	6.47	12.93	9.01	51.03	7.48	6.15	7.96	16.25
cloth	24.09	9.71	10.44	24.10	17.13	49.65	34.06	8.03	22.74	21.99
foot	23.22	23.14	16.78	37.34	8.93	41.56	18.92	29.82	37.69	12.17
rents	10.26	14.82	13.40	20.97	7.84	72.06	12.13	-	8.62	11.12
fuel	41.33	7.26	8.44	49.62	13.07	38.54	39.97	37.91	16.15	8.27
furniture	9.13	10.56	9.05	41.27	8.42	37.40	7.69	26.71	22.83	22.66
dom	9.85	36.81	8.31	28.65	7.33	17.78	8.12	32.32	30.88	15.50
vehicles	8.68	7.49	16.60	40.88	9.14	28.59	7.16	26.72	37.81	8.18
pubtrans	7.96	13.25	7.22	21.05	9.59	8.36	7.79	57.03	28.91	18.61
comm	14.40	6.70	8.91	13.62	16.19	21.60	8.20	11.90	30.05	15.99
sound	7.82	8.40	10.37	51.66	7.88	36.47	7.87	-	53.06	13.76
leisure	6.35	8.81	6.84	19.55	7.09	11.06	6.93	7.94	10.11	18.65
books	6.59	8.82	7.62	53.37	8.57	28.92	7.11	42.73	7.18	20.48
hotels	9.05	12.55	11.23	10.26	10.08	13.99	12.35	9.18	8.20	17.24

Notes: The results are calculated on the basis of 10,000 replications. T=180 data points were used. The data generating process is the SETAR model described in (6) calibrated using the estimation results for each country and sectors as is shown in table 2. Abbreviations for the countries are as follows: BE (Belgium), DK (Denmark), GE (Germany), GR (Greece), FR (France), IT (Italy), NE (Netherlands), SP (Spain), UK (United Kingdom)

Table 2. SETAR estimation results

	κ	ρ	d	hl SETAR	hl Linear	p-value H
			bread			
Belgium	0.097	0.969	6	22.0	39.5	0.205
Denmark	0.152	0.959	5	16.6	84.1	0.058
Germany	0.088	0.967	5	20.7	49.2	0.115
Greece	0.072	0.956	4	15.4	29.7	0.000
France	0.108	0.952	5	14.1	34.5	0.000
Italy	0.175	0.920	2	8.3	42.1	0.002
Netherlands	0.026	0.971	1	23.6	27.3	0.131
Portugal	0.359	0.690	4	1.9	61.0	0.509
Spain	0.391	0.804	1	3.2	141.8	0.130
UK	0.069	0.922	1	8.5	15.0	0.000
			meat			
Belgium	0.174	0.938	3	10.8	49.6	0.012
Denmark	0.194	0.895	2	6.2	44.9	0.000
Germany	0.032	0.978	4	31.2	63.5	0.100
Greece	0.043	0.940	6	11.2	20.0	0.000
France	0.063	0.970	6	22.8	51.1	0.339
Italy	0.072	0.956	4	15.4	36.2	0.000
Netherlands	0.051	0.969	4	22.0	39.9	0.000
Portugal	0.140	0.842	2	4.0	19.3	0.000
Spain	0.302	0.744	1	2.3	53.4	0.440
UK	0.046	0.895	3	6.2	11.4	0.000
			dairy			
Belgium	0.075	0.969	4	22.0	61.8	0.151
Denmark	0.255	0.841	3	4.0	80.0	0.018
Germany	0.116	0.956	5	15.4	62.5	0.001
Greece	0.294	0.834	3	3.8	42.5	0.162
France	0.099	0.959	5	16.6	51.3	0.001
Italy	0.203	0.931	4	9.7	76.9	0.008
Netherlands	0.105	0.962	5	17.9	50.9	0.000
Portugal	0.099	0.949	5	13.2	48.8	0.051
Spain	0.147	0.972	5	24.4	122.2	0.025
UK	0.104	0.943	1	11.8	24.5	0.000

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...table 2 continued

	κ	ρ	d	hl SETAR	hl Linear	p-value H
			fruit			
Belgium	0.025	0.858	1	4.5	5.2	0.000
Denmark	0.019	0.891	1	6.0	6.5	0.000
Germany	0.029	0.856	1	4.5	5.1	0.000
Greece	0.033	0.791	1	3.0	3.5	0.000
France	0.026	0.860	1	4.6	5.3	0.000
Italy	0.028	0.940	4	11.2	12.9	0.000
Netherlands	0.028	0.871	1	5.0	5.9	0.000
Portugal	0.052	0.890	1	5.9	7.7	0.000
Spain	0.150	0.862	6	4.7	11.6	0.000
UK	0.181	0.827	1	3.6	10.5	0.000
			tobac			
Belgium	0.254	0.928	1	9.3	38.3	0.001
Denmark	0.134	0.851	1	4.3	12.3	0.000
Germany	0.066	0.909	1	7.3	12.7	0.000
Greece	0.314	0.781	4	2.8	26.1	0.183
France	0.304	0.887	6	5.8	42.1	0.166
Netherlands	0.178	0.827	1	3.6	20.6	0.000
Portugal	0.276	0.768	6	2.6	22.1	0.000
Spain	0.276	0.768	1	2.6	15.5	0.022
UK	0.017	0.933	4	10.0	13.7	0.000
			alco			
Belgium	0.189	0.951	5	13.8	80.5	0.507
Denmark	0.065	0.969	4	22.0	50.5	0.211
Germany	0.135	0.979	5	32.7	92.8	0.123
Greece	0.337	0.854	4	4.4	124.3	0.405
France	0.160	0.956	5	15.4	73.5	0.030
Italy	0.309	0.835	1	3.8	83.3	0.623
Netherlands	0.117	0.968	5	21.3	57.3	0.251
Portugal	0.249	0.979	5	32.7	346.2	0.362
Spain	0.307	0.959	5	16.6	274.3	0.353
UK	0.186	0.920	4	8.3	39.4	0.050

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...table 2 continued

	κ	ρ	d	hl SETAR	hl Linear	p-value H
			cloth			
Belgium	0.404	0.892	3	6.1	1162.1	0.143
Denmark	0.132	0.951	4	13.8	47.7	0.000
Germany	0.245	0.946	3	12.5	231.3	0.026
Greece	0.223	0.816	5	3.4	24.3	0.000
France	0.309	0.915	3	7.8	162.9	0.250
Italy	0.295	0.838	6	3.9	89.3	0.022
Netherlands	0.061	0.872	6	5.1	7.8	0.007
Portugal	0.380	0.956	3	15.4	692.8	0.200
Spain	0.376	0.896	1	6.3	224.6	0.075
UK	0.070	0.901	1	6.6	11.0	0.000
			foot			
Belgium	0.363	0.895	3	6.2	342.9	0.296
Denmark	0.349	0.895	3	6.2	976.8	0.151
Germany	0.320	0.916	4	7.9	1393.1	0.260
Greece	0.244	0.782	6	2.8	36.1	0.170
France	0.221	0.956	2	15.4	168.4	0.031
Italy	0.304	0.854	1	4.4	109.2	0.018
Netherlands	0.032	0.910	2	7.3	8.2	0.000
Portugal	0.401	0.877	2	5.3	589.7	0.236
Spain	0.392	0.860	1	4.6	242.0	0.320
UK	0.036	0.938	1	10.8	13.6	0.000
			rents			
Belgium	0.284	0.946	2	12.5	95.0	0.115
Denmark	0.319	0.923	4	8.7	191.5	0.236
Germany	0.282	0.929	4	9.4	998.7	0.034
Greece	0.393	0.901	5	6.6	692.8	0.125
France	0.194	0.964	4	18.9	105.3	0.341
Italy	0.289	0.704	1	2.0	61.6	0.001
Netherlands	0.302	0.934	3	10.2	230.1	0.223
Spain	0.151	0.959	5	16.6	46.3	0.415
UK	0.186	0.942	2	11.6	41.7	0.325

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...table 2 continued

	κ	ρ	d	hl SETAR	hl Linear	p-value H
			fuel			
Belgium	0.157	0.856	1	4.5	22.3	0.000
Denmark	0.149	0.969	6	22.0	73.6	0.330
Germany	0.117	0.959	6	16.6	47.3	0.028
Greece	0.167	0.839	1	3.9	16.5	0.006
France	0.170	0.932	3	9.8	48.9	0.000
Italy	0.297	0.779	1	2.8	53.0	0.003
Netherlands	0.044	0.959	6	16.6	24.6	0.072
Portugal	0.246	0.862	2	4.7	67.0	0.002
Spain	0.144	0.920	5	8.3	35.1	0.000
UK	0.043	0.960	6	17.0	26.3	0.240
			furniture			
Belgium	0.198	0.955	4	15.1	90.9	0.014
Denmark	0.217	0.946	5	12.5	153.7	0.048
Germany	0.175	0.955	4	15.1	131.0	0.093
Greece	0.182	0.856	5	4.5	30.9	0.000
France	0.099	0.959	5	16.6	131.8	0.039
Italy	0.305	0.862	3	4.7	90.8	0.165
Netherlands	0.128	0.966	5	20.0	69.0	0.001
Portugal	0.426	0.804	4	3.2	578.5	0.647
Spain	0.365	0.817	4	3.4	144.4	0.157
UK	0.149	0.899	1	6.5	17.5	0.000
			dom			
Belgium	0.243	0.950	3	13.5	116.7	0.004
Denmark	0.315	0.863	3	4.7	108.9	0.107
Germany	0.167	0.961	6	17.4	113.6	0.010
Greece	0.107	0.884	5	5.6	16.2	0.000
France	0.113	0.969	5	22.0	68.3	0.291
Italy	0.234	0.914	2	7.7	77.0	0.016
Netherlands	0.149	0.962	5	17.9	66.7	0.020
Portugal	0.343	0.793	5	3.0	325.9	0.590
Spain	0.317	0.876	3	5.2	103.7	0.414
UK	0.096	0.923	1	8.7	16.9	0.000

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...table 2 continued

	κ	ρ	d	hl SETAR	hl Linear	p-value H
			vehicles			
Belgium	0.158	0.958	4	16.2	76.9	0.002
Denmark	0.156	0.967	6	20.7	123.8	0.368
Germany	0.294	0.917	3	8.0	881.1	0.095
Greece	0.177	0.857	1	4.5	11.1	0.002
France	0.168	0.954	4	14.7	100.2	0.001
Italy	0.246	0.804	1	3.2	47.5	0.003
Netherlands	0.169	0.970	5	22.8	145.4	0.163
Portugal	0.341	0.887	5	5.8	497.7	0.493
Spain	0.354	0.780	1	2.8	136.8	0.692
UK	0.036	0.961	4	17.4	24.0	0.228
			pubtrans			
Belgium	0.089	0.963	1	18.4	31.1	0.063
Denmark	0.201	0.931	4	9.7	87.8	0.021
Germany	0.064	0.971	5	23.6	38.8	0.048
Greece	0.064	0.904	3	6.9	12.0	0.000
France	0.090	0.951	4	13.8	28.8	0.001
Italy	0.125	0.960	4	17.0	51.9	0.345
Netherlands	0.078	0.964	3	18.9	39.4	0.167
Portugal	0.243	0.627	3	1.5	23.1	0.000
Spain	0.331	0.802	4	3.1	84.3	0.671
UK	0.117	0.911	1	7.4	14.2	0.023
			comm			
Belgium	0.117	0.927	1	9.1	17.4	0.000
Denmark	0.045	0.976	1	28.5	35.0	0.056
Germany	0.048	0.956	1	15.4	20.6	0.000
Greece	0.257	0.929	1	9.4	24.8	0.000
France	0.038	0.920	1	8.3	10.4	0.001
Italy	0.094	0.902	1	6.7	14.2	0.001
Netherlands	0.044	0.961	1	17.4	21.1	0.051
Portugal	0.030	0.939	1	11.0	12.2	0.000
Spain	0.200	0.880	3	5.4	23.0	0.000
UK	0.103	0.921	1	8.4	14.0	0.040

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...table 2 continued

	κ	ρ	d	hl SETAR	hl Linear	p-value H
			sound			
Belgium	0.106	0.964	4	18.9	37.6	0.348
Denmark	0.102	0.959	5	16.6	35.9	0.004
Germany	0.190	0.947	2	12.7	110.8	0.075
Greece	0.211	0.835	2	3.8	24.2	0.007
France	0.059	0.964	4	18.9	30.3	0.005
Italy	0.260	0.865	3	4.8	51.9	0.022
Netherlands	0.051	0.964	4	18.9	27.5	0.032
Spain	0.307	0.746	1	2.4	50.0	0.291
UK	0.109	0.930	3	9.6	41.2	0.041
			leisure			
Belgium	0.037	0.979	6	32.7	47.1	0.115
Denmark	0.166	0.957	5	15.8	78.8	0.370
Germany	0.085	0.975	6	27.4	58.6	0.076
Greece	0.295	0.908	2	7.2	57.3	0.221
France	0.061	0.973	1	25.3	35.6	0.233
Italy	0.230	0.942	1	11.6	59.0	0.000
Netherlands	0.032	0.974	1	26.3	31.5	0.123
Portugal	0.069	0.963	1	18.4	27.6	0.101
Spain	0.206	0.949	5	13.2	70.8	0.167
UK	0.125	0.911	1	7.4	16.6	0.003
			books			
Belgium	0.112	0.978	6	31.2	59.2	0.141
Denmark	0.182	0.957	5	15.8	95.3	0.372
Germany	0.113	0.967	5	20.7	59.4	0.007
Greece	0.388	0.744	1	2.3	153.1	0.428
France	0.088	0.958	5	16.2	30.0	0.001
Italy	0.243	0.882	2	5.5	67.3	0.017
Netherlands	0.034	0.972	1	24.4	28.6	0.000
Portugal	0.370	0.767	5	2.6	99.5	0.489
Spain	0.134	0.970	6	22.8	59.3	0.423
UK	0.144	0.904	1	6.9	20.0	0.000

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...table 2 continued

	κ	ρ	d	hl SETAR	hl Linear	p-value H
			hotels			
Belgium	0.062	0.955	3	15.1	18.9	0.039
Denmark	0.029	0.936	1	10.5	12.5	0.024
Germany	0.025	0.942	1	11.6	12.8	0.027
Greece	0.036	0.945	2	12.3	15.2	0.014
France	0.034	0.948	4	13.0	17.3	0.000
Italy	0.087	0.929	4	9.4	24.7	0.043
Netherlands	0.023	0.937	1	10.7	11.7	0.015
Portugal	0.134	0.954	4	14.7	39.7	0.000
Spain	0.127	0.961	4	17.4	45.4	0.020
UK	0.033	0.916	1	7.9	8.4	0.005

Notes: This table shows the result from the estimation of the SETAR (1, 2, d) model in equation (6). κ is the value of the threshold, ρ is the autoregressive parameter, which measures the degree of mean reversion, and d is the delay parameter. The estimation of κ, ρ and d is done simultaneously via a grid search over κ and d as is described in section 3. hl SETAR is the half-life implied by the SETAR model. It is calculated as hl=ln0.5/lnρ. hl Linear refers to the half-life implied by the estimation of the AR(1) model in equation (16). The p-value H is the marginal significance level of the Hansen(1997) linearity test.

APPENDIX: SETAR Results with UK Pound as Reference Currency

	κ	ρ	d	hl SETAR	hl Linear	p-value H
			bread			
Belgium	0.183	0.914	6	7.708	99.795	0.000
Denmark	0.227	0.862	2	4.668	63.288	0.001
Germany	0.133	0.971	5	23.553	346.227	0.624
Greece	0.022	0.962	2	17.892	24.347	0.114
France	0.123	0.884	5	5.622	35.653	0.000
Italy	0.055	0.903	5	6.793	16.678	0.000
Netherlands	0.095	0.917	6	8.000	32.011	0.023
Portugal	0.248	0.886	3	5.727	29.986	0.131
Spain	0.263	0.831	2	3.744	74.855	0.000
US	0.069	0.922	1	8.535	14.960	0.000
			meat			
Belgium	0.137	0.915	5	7.803	74.001	0.000
Denmark	0.100	0.940	2	11.202	38.121	0.027
Germany	0.033	0.969	5	22.011	56.359	0.520
Greece	0.016	0.943	4	11.811	17.243	0.149
France	0.156	0.857	5	4.492	46.528	0.000
Italy	0.052	0.894	5	6.186	20.397	0.000
Netherlands	0.184	0.793	6	2.989	39.144	0.000
Portugal	0.026	0.932	5	9.843	15.461	0.036
Spain	0.118	0.954	4	14.719	34.023	0.049
US	0.046	0.895	3	6.248	11.396	0.000
			dairy			
Belgium	0.069	0.865	4	4.779	15.187	0.000
Denmark	0.080	0.854	5	4.392	15.728	0.000
Germany	0.037	0.895	2	6.248	12.024	0.000
Greece	0.121	0.806	2	3.214	19.021	0.000
France	0.081	0.770	5	2.652	10.856	0.000
Italy	0.107	0.876	6	5.236	18.142	0.080
Netherlands	0.037	0.883	2	5.571	11.325	0.000
Portugal	0.114	0.825	2	3.603	10.580	0.020
Spain	0.160	0.785	2	2.863	26.140	0.000
US	0.104	0.943	1	11.811	24.451	0.000

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	κ	ρ	d	hl SETAR	hl Linear	p-value H
			fruit			
Belgium	0.050	0.775	2	2.719	5.195	0.000
Denmark	0.182	0.677	1	1.777	18.314	0.000
Germany	0.045	0.907	4	7.101	11.257	0.000
Greece	0.047	0.715	1	2.066	3.008	0.001
France	0.113	0.809	6	3.270	12.934	0.000
Italy	0.100	0.921	6	8.423	17.255	0.000
Netherlands	0.092	0.802	3	3.141	10.067	0.002
Portugal	0.085	0.787	5	2.894	8.575	0.000
Spain	0.154	0.834	6	3.819	13.559	0.000
US	0.181	0.827	1	3.649	10.523	0.000
			tobac			
Belgium	0.106	0.941	5	11.398	55.561	0.185
Denmark	0.021	0.913	1	7.615	9.081	0.044
Germany	0.036	0.853	5	4.360	8.573	0.000
Greece	0.088	0.899	4	6.510	20.964	0.000
France	0.017	0.985	1	45.862	45.949	0.280
Netherlands	0.108	0.798	5	3.072	21.384	0.000
Portugal	0.175	0.798	6	3.072	21.254	0.000
Spain	0.068	0.856	5	4.458	9.878	0.000
US	0.043	0.931	4	9.695	13.744	0.000
			alco			
Belgium	0.018	0.950	1	13.513	17.824	0.038
Denmark	0.047	0.863	6	4.704	16.139	0.000
Germany	0.021	0.947	5	12.729	17.094	0.008
Greece	0.198	0.802	3	3.141	41.895	0.000
France	0.024	0.941	1	11.398	15.959	0.140
Italy	0.065	0.809	6	3.270	16.136	0.000
Netherlands	0.026	0.926	4	9.016	16.260	0.033
Portugal	0.181	0.984	6	42.974	942.597	0.329
Spain	0.163	0.821	6	3.514	130.160	0.019
US	0.186	0.920	4	8.313	39.413	0.050

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	κ	ρ	d	hl SETAR	hl Linear	p-value H
			cloth			
Belgium	0.295	0.920	5	8.313	148.784	0.052
Denmark	0.246	0.903	2	6.793	36.523	0.000
Germany	0.268	0.780	6	2.790	56.410	0.004
Greece	0.314	0.655	5	1.638	16.373	0.144
France	0.317	0.714	5	2.058	61.768	0.230
Italy	0.129	0.951	5	13.684	29.346	0.054
Netherlands	0.063	0.847	2	4.174	8.238	0.000
Portugal	0.372	0.843	5	4.059	136.060	0.196
Spain	0.267	0.885	2	5.674	56.910	0.297
US	0.070	0.901	1	6.642	10.969	0.000
			foot			
Belgium	0.264	0.864	6	4.742	70.383	0.025
Denmark	0.239	0.931	1	9.695	73.178	0.005
Germany	0.283	0.819	6	3.471	43.810	0.001
Greece	0.315	0.700	5	1.943	15.837	0.170
France	0.272	0.752	5	2.432	48.818	0.127
Italy	0.096	0.956	4	15.404	27.010	0.158
Netherlands	0.119	0.848	6	4.204	4.950	0.001
Portugal	0.276	0.944	6	12.028	377.139	0.169
Spain	0.236	0.903	2	6.793	42.793	0.165
US	0.036	0.938	1	10.830	13.557	0.000
			rents			
Belgium	0.139	0.909	1	7.265	24.169	0.056
Denmark	0.109	0.922	6	8.535	26.410	0.070
Germany	0.136	0.934	5	10.152	34.899	0.100
Greece	0.065	0.989	6	62.666	86.158	0.199
France	0.140	0.741	6	2.312	20.118	0.055
Italy	0.030	0.926	2	9.016	14.418	0.194
Netherlands	0.033	0.978	6	31.159	38.998	0.103
Spain	0.128	0.945	3	12.253	12.253	0.114
US	0.216	0.942	2	11.601	41.724	0.325

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	κ	ρ	d	hl SETAR	hl Linear	p-value H
			fuel			
Belgium	0.013	0.928	4	9.276	10.636	0.000
Denmark	0.129	0.786	1	2.879	20.451	0.000
Germany	0.084	0.750	6	2.409	12.162	0.011
Greece	0.020	0.920	1	8.313	9.751	0.004
France	0.020	0.920	4	8.313	13.144	0.034
Italy	0.066	0.876	5	5.236	15.815	0.000
Netherlands	0.024	0.881	5	5.471	10.032	0.008
Portugal	0.114	0.883	6	5.571	13.874	0.017
Spain	0.041	0.794	1	3.005	6.198	0.000
US	0.043	0.960	6	16.980	26.343	0.240
			furniture			
Belgium	0.102	0.894	5	6.186	46.562	0.003
Denmark	0.137	0.867	5	4.857	32.412	0.081
Germany	0.179	0.714	6	2.058	25.962	0.067
Greece	0.111	0.651	6	1.615	8.069	0.071
France	0.164	0.779	5	2.775	34.759	0.016
Italy	0.088	0.917	5	8.000	24.564	0.000
Netherlands	0.079	0.870	5	4.977	21.756	0.000
Portugal	0.289	0.875	6	5.191	86.145	0.213
Spain	0.181	0.804	5	3.177	36.786	0.036
US	0.149	0.899	1	6.510	17.529	0.000
			dom			
Belgium	0.178	0.818	5	3.450	62.972	0.015
Denmark	0.117	0.878	2	5.327	29.297	0.013
Germany	0.195	0.647	6	1.592	36.574	0.048
Greece	0.027	0.752	5	2.432	4.418	0.024
France	0.126	0.674	5	1.757	26.503	0.000
Italy	0.045	0.942	5	11.601	25.011	0.127
Netherlands	0.100	0.841	5	4.003	29.829	0.000
Portugal	0.256	0.835	3	3.844	95.098	0.251
Spain	0.164	0.841	2	4.003	34.903	0.001
US	0.096	0.923	1	8.651	16.932	0.000

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	κ	ρ	d	hl SETAR	hl Linear	p-value H
			vehicles			
Belgium	0.028	0.944	5	12.028	27.213	0.039
Denmark	0.069	0.930	4	9.551	30.279	0.001
Germany	0.068	0.939	5	11.013	43.036	0.017
Greece	0.177	0.798	1	3.072	32.919	0.285
France	0.116	0.761	5	2.538	33.469	0.046
Italy	0.093	0.890	5	5.948	17.276	0.000
Netherlands	0.085	0.915	5	7.803	37.294	0.036
Portugal	0.178	0.930	6	9.551	151.651	0.265
Spain	0.123	0.836	5	3.870	35.127	0.002
US	0.036	0.961	4	17.424	24.006	0.228
			pubtrans			
Belgium	0.112	0.833	6	3.793	26.734	0.000
Denmark	0.192	0.748	5	2.387	27.148	0.013
Germany	0.026	0.917	5	8.000	15.873	0.011
Greece	0.098	0.727	4	2.174	6.960	0.019
France	0.018	0.919	5	8.206	14.396	0.000
Italy	0.086	0.917	5	8.000	18.601	0.002
Netherlands	0.123	0.753	6	2.443	19.568	0.051
Portugal	0.118	0.767	5	2.613	11.129	0.000
Spain	0.120	0.860	2	4.596	27.028	0.004
US	0.117	0.911	1	7.436	14.288	0.023
			comm			
Belgium	0.184	0.960	5	16.980	346.227	0.180
Denmark	0.245	0.927	2	9.144	93.376	0.012
Germany	0.177	0.963	5	18.385	346.227	0.110
Greece	0.055	0.636	6	1.532	28.147	0.022
France	0.017	0.974	1	26.311	28.214	0.156
Italy	0.045	0.918	5	8.101	16.070	0.000
Netherlands	0.162	0.975	4	27.378	346.227	0.125
Portugal	0.044	0.953	5	14.398	24.420	0.120
Spain	0.043	0.959	2	16.557	33.954	0.103
US	0.103	0.921	1	8.423	14.031	0.040

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	κ	ρ	d	hl SETAR	hl Linear	p-value H
			sound			
Belgium	0.099	0.927	5	9.144	57.062	0.001
Denmark	0.098	0.963	5	18.385	72.948	0.110
Germany	0.027	0.988	4	57.415	99.992	0.210
Greece	0.139	0.814	6	3.368	15.043	0.028
France	0.087	0.923	5	8.651	60.323	0.053
Italy	0.057	0.921	5	8.423	23.511	0.078
Netherlands	0.091	0.896	6	6.312	24.676	0.004
Spain	0.066	0.916	5	7.900	27.810	0.000
US	0.109	0.930	3	9.551	41.167	0.041
			leisure			
Belgium	0.142	0.812	5	3.328	29.869	0.000
Denmark	0.087	0.919	5	8.206	21.956	0.058
Germany	0.022	0.944	6	12.028	22.143	0.144
Greece	0.020	0.973	1	25.324	26.258	0.165
France	0.073	0.877	4	5.281	17.405	0.000
Italy	0.062	0.938	5	10.830	23.905	0.209
Netherlands	0.023	0.934	4	10.152	17.471	0.176
Portugal	0.008	0.891	1	6.006	6.682	0.182
Spain	0.105	0.846	4	4.145	26.677	0.000
US	0.125	0.911	1	7.436	16.625	0.003
			books			
Belgium	0.095	0.934	5	10.152	72.981	0.005
Denmark	0.041	0.978	5	31.159	58.473	0.179
Germany	0.020	0.960	5	16.980	29.373	0.174
Greece	0.225	0.889	6	5.891	68.849	0.065
France	0.028	0.895	5	6.248	13.559	0.000
Italy	0.028	0.951	5	13.796	24.301	0.154
Netherlands	0.018	0.938	6	10.830	17.947	0.138
Portugal	0.261	0.858	1	4.526	88.448	0.039
Spain	0.087	0.880	1	5.422	11.381	0.000
US	0.144	0.904	1	6.868	20.044	0.000

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	κ	ρ	d	hl SETAR	hl Linear	p-value H
			hotels			
Belgium	0.097	0.914	6	7.708	54.458	0.000
Denmark	0.058	0.907	4	7.101	16.489	0.000
Germany	0.026	0.916	5	7.900	15.466	0.035
Greece	0.042	0.937	5	10.652	18.987	0.006
France	0.064	0.861	5	4.631	21.098	0.001
Italy	0.136	0.846	6	4.145	19.654	0.000
Netherlands	0.030	0.920	5	8.313	15.568	0.082
Portugal	0.106	0.962	4	17.892	71.035	0.111
Spain	0.174	0.853	2	4.360	34.736	0.008
US	0.033	0.916	1	7.900	8.441	0.005

Notes: This table shows the result from the estimation of the SETAR (1, 2, d) model in equation (6). κ is the value of the threshold, ρ is the autoregressive parameter, which measures the degree of mean reversion, and d is the delay parameter. The estimation of κ, ρ and d is done simultaneously via a grid search over κ and d as is described in section 3. hl SETAR is the half-life implied by the SETAR model. It is calculated as hl=ln0.5/lnρ. hl Linear refers to the half-life implied by the estimation of the AR(1) model in equation (16). The p-value H is the marginal significance level of the Hansen(1997) linearity test.