Purchasing Power Parity in Tradable Goods*†

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Abstract

A vast body of empirical research documents the linkage between nominal exchange rates and relative prices across countries. While excellent surveys exist in the academic literature on this topic, they focus largely or entirely on broad baskets of prices and, most commonly, on the consumer price index. The present survey focuses mainly on internationally tradable goods and services, rather than broad baskets of goods and services that also include a substantial nontradable component. Specifically, the objective of this paper is to distill the empirical literature on the properties of deviations from the law of one price applied to internationally tradable goods or sectors – i.e. the proposition that price levels of similar goods, expressed in a common currency, have a tendency to equalize over time. We conclude that a careful reading of the literature suggests that this notion of PPP holds in the long run for a broad range of tradable goods and services and for a broad set of currencies. In turn, one implication is that the exchange rate risk for a long-horizon investor is relatively small.

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1 Introduction

In this study we provide a discussion of the basic building block of purchasing power parity (PPP), the law of one price (LOP). The LOP relates to the common-currency prices of similar goods at a disaggregated level, postulating that similar tradable goods, once their national prices are expressed in a common currency, should sell for the same price across different international locations. Aggregating across different tradable goods and services in a sector and then across different sectors, one obtains that the resulting baskets of tradable goods should trade at the same price: this is the notion of PPP in tradable goods. Further aggregating across other goods and services, including nontradables, leads to the conventional PPP hypothesis, which states that national price levels should be equal when expressed in a common currency.

While several surveys exist on PPP, this paper focuses mainly on internationally tradable goods and services, rather than broad baskets of goods and services that also include a substantial nontradable component. Specifically, the objective is to understand the properties of deviations from the LOP applied to internationally tradable goods or sectors, on the basis of the existing empirical evidence published in the leading academic literature. To anticipate our conclusion, we will show that a careful reading of the literature suggests that the LOP holds over long periods of time for the relevant tradable goods and services, and that adjustment occurs in a nonlinear fashion such that the larger the deviation from parity in the past the faster the adjustment towards parity in the future.

The study begins with a brief introduction that outlines the economic foundations and the definitions of PPP and the LOP. It then briefly summarizes the current consensus in the profession with respect to the validity of long-run PPP applied to broad baskets of goods and services, largely relying on existing surveys, such as those by Sarno and Taylor (2002), Taylor and Taylor (2004) and Sarno (2008). Starting from PPP is useful since the general economic and econometric issues surrounding PPP deviations are the same as those for the LOP; however, the vast majority of studies in this area of research focus on PPP and hence provide guidance on understanding the validity of the LOP too.

The core part of the survey focuses on the specific subset of the relevant literature that analyzes deviations from the LOP applied to individual goods and services and specific sectors. The emphasis will therefore be on tradable items. This literature, while less voluminous than the literature on PPP, is nevertheless substantial and it has not been summarized in a survey article to date. This is exactly the gap that this study fills, with the ultimate goal to describe the current state of knowledge on the properties of deviations from the LOP, including the persistence of deviations from the LOP across currencies (the speed of reversion to the LOP), and the nature of the shocks. In turn, the conclusions emerging from such distilled reading of the literature will allow one to draw conclusions with respect to the relevance of exchange rate risk for a long-horizon investor in international asset allocation decisions. In short, the discussion will follow similar steps as the leading surveys on PPP, but with a more specific focus on internationally tradable goods and a specific description of some of the key studies that have best addressed this topic.

The remainder of this paper is set out as follows. Section 2 provides a review of the literature on PPP as a useful preliminary, whereas Section 3 defines the LOP for tradable goods and its link to PPP. Section 4 provides an overview of the relevant empirical literature on the LOP, followed by a further discussion in Section 5. A final section briefly summarizes and concludes.

2 PPP: Theory and Evidence

The PPP hypothesis states that national price levels should be equal when expressed in a common currency. Although very few economists would believe that this simple proposition holds at each point in time, a large literature in international finance has examined empirically the validity of PPP over the long-run, either by testing whether nominal exchange rates and relative prices move together or by testing whether the real exchange rate has a tendency to revert to a stable equilibrium level over time. The latter approach is motivated by the fact that the real exchange rate may be defined as the nominal exchange rate adjusted for relative national price levels (see the surveys of Rogoff, 1996; Sarno and Taylor, 2002; Taylor and Taylor, 2004; Sarno, 2008).

Indeed, whether long-run PPP holds or whether the real exchange rate is stationary has important economic implications on a number of fronts. In particular, the degree of persistence in the real exchange rate can be used to infer the principal impulses driving exchange rate movements.[1] Further, from a theoretical perspective, if PPP is not a valid long-run international parity condition, this casts doubts on the predictions of much open-economy macroeconomics that is based on the assumption of long-run PPP. Finally, estimates of PPP exchange rates are often used for practical purposes such as determining the degree of misalignment of the nominal exchange rate and the appropriate policy response, the setting of exchange rate parities, the international comparison of national income levels, and the need for exchange rate hedging for a long-run investor. These practical uses of the PPP concept, and in particular the calculation of PPP exchange rates, would obviously be of very limited use if PPP deviations do not settle down to a constant equilibrium level over time.[2]

It should be clear from this discussion that we take a commodity-arbitrage view to rationalize the validity of long-run PPP, as popularized, for example, by Samuelson (1964). An older view of PPP is the Cassellian view, according to which the appropriate definition of the price level for implementing PPP is the general price level, and whether or not the price level samples nontradable goods is irrelevant (Cassell, 1922). Cassel's idea is that PPP refers to the internal value of the currencies concerned, which can be measured using the general price level. While the Cassellian view is still somewhat extant in the profession, our reading of the recent theoretical and empirical

[1] For example, if the real exchange rate is highly persistent, then the shocks are likely to be real-side, e.g. technology shocks, whereas if it is not very persistent, then the shocks must be mainly to aggregate demand, such as, for example, monetary policy shocks (Rogoff, 1996).

[2] It is also worth noting that the literature refers to the difficulty sometimes encountered in establishing very strong evidence in favor of PPP as the 'PPP puzzle' (Rogoff, 1996). This terminology suggests that, should PPP not hold, it would be regarded as an anomaly, a surprising empirical fact, given that international economists tend to believe that some sort of PPP must guide the long-run comovement between exchange rates and relative prices.

literature on PPP is, however, that most experts in international finance who believe in the validity of long-run PPP take the commodity-arbitrage view.

An important point to note is that, in testing PPP, most studies in the literature have employed official price indices. If real exchange rate adjustment towards the PPP equilibrium is driven by arbitrage in international goods markets, however, the appropriate price index to be used in implementing PPP is of crucial importance. In particular, all commonly used price indices include some proportion of nontradable goods, for which arbitrage does not occur. However, some work on PPP looks at the cost of production of a basket of goods–producer choices (rather than the cost of a basket of goods in terms of consumer choices). For example, Lafrance, Osakwe and Normandin (1998) and Sarno and Chowdhury (2003) provide evidence that PPP works much better if it is based on costs of production–essentially unit labor costs–or on indices made only of tradable goods, rather than e.g. the consumer price index (CPI) from official sources. These papers empirically support the validity of PPP in tradable goods, and we shall discuss them later in the paper.

One well-documented explanation for the inability to find clear-cut evidence of PPP is the low power of conventional statistical tests applied in this context with a sample span corresponding to the length of the recent float since the early 1970s (e.g. Sarno and Taylor, 2002).[3] Researchers have sought to overcome the power problem in testing for mean reversion in the real exchange rate either using long span studies (e.g. Lothian and Taylor, 1996; Taylor, 2002) or more powerful panel econometric methods (e.g. Abuaf and Jorion, 1990; Frankel and Rose, 1996; O'Connell, 1998; Papell, 1998; Sarno and Taylor, 1998; Taylor and Sarno, 1998). However, whether or not the long-span or panel-data studies do in fact answer the question whether PPP holds in the long run remains contentious, given the mixed results provided by this subset of the literature.[4]

In the procedures conventionally applied to test for long-run PPP, the null hypothesis is usually that the process generating the real exchange rate series is linear, which means that adjustment is both continuous and of constant speed, regardless of the size of the deviation from PPP. However, the presence of transaction costs implies a nonlinear process, which has important implications for tests of long-run PPP. A number of authors have developed theoretical models of nonlinear real exchange rate adjustment arising from transaction costs in international arbitrage. These models are discussed in greater detail later in this study but, for the moment, it suffices to note that they suggest that the exchange rate will become increasingly mean reverting with the size of the

[3] In an illustrative Monte Carlo exercise, Sarno and Taylor (2002) show how, given the observed persistence properties of the real exchange rate, standard unit root tests may be unable to detect stationarity of the real exchange rate (i.e. the validity of long-run PPP), having less than a 50/50 chance to do so for samples spanning up to 100 years. The same problem applies to the LOP (Taylor, 2001).

[4] As far as the long-span studies are concerned, as noted in particular by Frankel and Rose (1996), the long samples required to generate a reasonable level of statistical power with standard univariate unit root tests may be unavailable for many currencies (perhaps thereby generating a 'survivorship bias' in tests on the available data) and, in any case, may potentially be inappropriate because of differences in real exchange rate behavior both across different historical periods and across different nominal exchange rate regimes (e.g. Baxter and Stockman, 1989; Taylor, 2002). As for panel-data studies, these provide mixed evidence. While, for example, Frankel and Rose (1996) and Taylor and Sarno (1998) find results favorable to long-run PPP, O'Connell (1998) rejects it on the basis of his empirical evidence.

deviation from the PPP equilibrium level. The arguments made here to rationalize mean reversion in the real exchange rates towards PPP are based on ideas that relate to the LOP in the sense that they refer to tradable goods only.[5]

We now turn to the empirical evidence on nonlinear mean reversion in real exchange rates. Michael, Nobay and Peel (1997) apply a nonlinear model to monthly interwar data for the French franc-US dollar, French franc-UK sterling and UK sterling-US dollar as well as for the Lothian and Taylor (1996) long span data set for 200 years ending in 1992. The systematic pattern in the estimates of the nonlinear models provides strong evidence of mean-reverting behavior for PPP deviations. Using data for the recent float, moreover, Taylor, Peel and Sarno (TPS) (2001) provide confirmation that four major real bilateral dollar exchange rates are well characterized by nonlinearly mean reverting processes. The estimated model implies an equilibrium level of the real exchange rate in the neighborhood of which the real exchange rate is close to a random walk, becoming increasingly mean reverting with the absolute size of the deviation from equilibrium, consistent with the theoretical arguments on the nature of real exchange rate dynamics in the presence of international arbitrage costs.

TPS also estimate the impulse response functions corresponding to their estimated nonlinear real exchange rate models.[6] By taking account of nonlinearities, TPS find the speed of real exchange rate adjustment to be typically much faster than the very slow speeds of real exchange rate adjustment hitherto recorded in the literature. For example, the estimated half lives (in months) for dollar-sterling and dollar-yen are the following

Shock (%):	40	30	20	10	5	1
dollar-sterling	10	20	22	26	29	32
dollar-yen	14	18	24	32	38	42

where in the first row we report the size of the shock (in percentage terms) to the log-level of the real exchange rate. The estimated half lives of these major real dollar exchange rates illustrate the nonlinear nature of the response to shocks, with larger shocks mean reverting much faster than smaller shocks. The dollar-sterling rate displays quite fast mean reversion, ranging from a half life of under one year for the largest shocks of forty percent to just under three years for small shocks of one percent; for shocks of five to ten percent, the half lives are just over two years. The dollar-yen displays higher persistence, with half lives ranging from fourteen to forty-two months.

[5] However, we argue that this is reasonable given that Engel (1999), in a study that measures the proportion of dollar real exchange rate movements that can be accounted for by movements in the relative prices of nontradable goods, finds that relative prices of nontradable goods appear to account for essentially none of the movement of dollar real exchange rates. Hence, much of the explanation for the time series properties of PPP deviations is likely to reside in the behavior of deviations from the LOP–i.e. movements in the relative prices of tradable goods.

[6] Note that the results of TPS (2001) have been checked for robustness and extended to a large number of currencies and case studies. The paper by TPS (2001) has been cited 189 times in published papers in journals listed in the Social Science Citation Index (SSCI) as of February 2011, whereas Google Scholar (which also includes working papers and books) reports 430 citations. Most of these papers have extended the results in TPS to other currencies or sample periods, or further generalized the model.

These results therefore suggest that not only PPP holds among major economies, but only for small shocks occurring when the real exchange rate is near its equilibrium do nonlinear models consistently yield half lives in the range of three to five years, which Rogoff (1996) terms 'glacial.' For dollar-sterling, even small shocks of one to five percent have a half life under three years; for larger shocks, the speed of mean reversion is even faster. Sarno and Chowdhury (2003) apply the same methods as TPS (2001) to real exchange rates constructed using only tradable goods, and report even faster adjustment to PPP.[7]

A further generalization of this class of models is provided by Sarno and Valente (2006), who use long-span data and apply a general modelling methodology in which regime changes and nonlinearities in the dynamic relationship between exchange rates and prices are explicitly allowed for. They examine the G5 countries across different exchange rate regimes, including the gold standard, the Bretton Woods period, and the floating regime since the 1970s. Over the sample period examined, the economic history of the countries involved has seen a number of fundamental changes in monetary and exchange rate regimes, institutional structure and policy targets which, in addition to the continuous evolution of the financial system and various nominal and real shocks, represent serious potential pitfalls to researchers attempting to find an empirical model of the deviations from PPP that is stable over the full sample. Sarno and Valente's results are supportive of long-run PPP for each of the major exchange rates examined and of a simple basic conjecture: under fixed exchange rate regimes relative prices adjust to restore deviations from long-run equilibrium, while nominal exchange rates bear most of the burden of adjustment under flexible exchange rate regimes. However, the validity of long-run PPP does not depend on the regime in operation, only its dynamics does.

Overall, our reading of the literature suggests that PPP is a good first approximation to the long-run behavior of exchange rates, and that adjustment to PPP displays significant nonlinearities.[8] Before turning to the LOP and the empirical literature on the validity of the LOP, it is worth to put PPP in the broader context of exchange rate determination. Clearly there is more to exchange rate determination than relative prices across countries, and indeed the economic fundamentals suggested by international macroeconomic theories are many. They include, for example, the 'monetary fundamentals', comprising the differential in money supply and the differential in output, consistent with flexible-price models (Mark, 1995); net foreign assets (e.g. Cavallo and Ghironi, 2002; Gourinchas and Rey, 2005); the trade balance, as suggested by portfolio balance models (e.g. Branson, 1984; Kumhof and Van Nieuwerburgh, 2005) and elasticity models of the balance of trade (e.g. Krueger, 1983; Rose and Yellen, 1989; Obstfeld and Rogoff, 2007). Further-

[7] An interesting experiment in terms of gauging the extent to which market integration and the reduction of trade costs impacts on the degree of mean reversion in real exchange rates is provided by the advent of the euro in 1999. Koedijk, Tims and van Dijk (2004) provide empirical evidence that the introduction of the euro and, more generally, the process of economic integration in Europe has accelerated convergence to PPP, consistent with a transactions-costs goods-market arbitrage view of PPP. Future research on these data is warranted to refine the estimates of Koedijk, Tims and van Dijk and test for nonlinearities.

[8] Note that, while the initial results in this literature were established using data for major currencies, their robustness has been extended to a number of emerging currencies. We detail studies on emerging markets later in the paper.

more, Andersen, Bollerslev, Diebold and Vega (2003) and Rime, Sarno and Sojli (2010) document that the set of macroeconomic news that affect exchange rates in the short-run is quite broad, including money, income, prices and a number of other macroeconomic variables. Finally, microstructure theories suggest that order flow (the net of buy and sell transactions for a currency) is a powerful determinant of exchange rate fluctuations both in the short- (Evans and Lyons, 2002) and long-run (Chinn and Moore, 2011). Stating that PPP holds does not discredit any of these models; to the contrary, it is consistent with them since these theories are generally based on the assumption that in the long-run PPP (the LOP) holds among tradable goods, while in the short- and medium-term there are other forces playing a role.

3 The LOP and Price Indices

The LOP states that identical goods, once their national prices are expressed in a common currency, should sell for the same price across different international locations. The LOP is viewed as a long-run proposition about arbitrage in international goods markets that suggests that once arbitrage opportunities arise they do not persist forever; adjustment can take place either via prices or via the exchange rate, which moves in such a way to restore the LOP over time. While in its purest form the LOP compares *identical* products or services sold in two different geographical locations, the most relevant case in practice is the comparison of *similar* goods, with different origin of production and different pricing currency, for which prices should be very close, after accounting for transaction costs, due to competition in international goods markets.

Ignoring transaction costs for the moment, the LOP stated above in its *absolute* version may be written formally as:

$$P_{i,t} = S_t P^*_{i,t} \qquad i = 1, 2, \ldots, N \tag{1}$$

where $P_{i,t}$ denotes the price of good i in terms of the domestic currency at time t, $P^*_{i,t}$ is the price of good i in terms of the foreign currency at time t, and S_t is the nominal exchange rate expressed as the domestic price of the foreign currency at time t. In its *relative* version, the LOP postulates the relatively weaker condition:

$$\frac{P^*_{i,t+1} S_{t+1}}{P_{i,t+1}} = \frac{P^*_{i,t} S_t}{P_{i,t}} \qquad i = 1, 2, \ldots, N. \tag{2}$$

Obviously, the absolute LOP implies the relative LOP, but not *vice versa*.

By summing up all the traded goods in each country, one obtains the *absolute* version of PPP for tradable goods:

$$\textstyle\sum_{i=1}^{N} \alpha_i P_{i,t} = S_t \sum_{i=1}^{N} \alpha_i P^*_{i,t}, \tag{3}$$

where the weights in the summation satisfy $\sum_{i=1}^{N} \alpha_i = 1$. Alternatively, if the price indices are constructed using a geometric index, then we must form the weighted sum after taking logarithms:

$$\textstyle\sum_{i=1}^{N} \gamma_i p_{i,t} = s_t + \sum_{i=1}^{N} \gamma_i p^*_{i,t}, \tag{4}$$

where the geometric weights in the summation satisfy $\sum_{i=1}^{N} \gamma_i = 1$ and lower case letters denote logarithms. If the aggregate price levels are P_t and P_t^* or, in logarithms, p_t and p_t^*, then (according to whether the arithmetic or geometric index is used), we can use (3) or (4) to derive the (absolute) PPP condition:

$$s_t = p_t - p_t^*. \tag{5}$$

From equation (5) it is easily seen that the real exchange rate, defined here in logarithmic form:

$$q_t \equiv s_t - p_t + p_t^*, \tag{6}$$

may be viewed as a measure of the deviation from PPP.

Clearly, deriving PPP for tradable goods from the LOP introduces a range of index number problems. For example, equations (3) and (4) implicitly assume that the same weights are relevant in each country, whereas price index weights will typically differ across countries (perhaps even being zero in one country and non-zero in another for some goods and services) and will also tend to shift through time. In practice, researchers often assume that PPP should hold approximately using the price indices of each country. In the geometric index case, for example, we can rearrange (4) to yield:

$$\sum_{i=1}^{N} \gamma_i p_{i,t} = s_t + \sum_{i=1}^{N} \gamma_i^* p_{i,t}^* + \sum_{i=1}^{N} (\gamma_i - \gamma_i^*) p_{i,t}^* \tag{7}$$

or

$$\sum_{i=1}^{N} \gamma_i p_{i,t} = s_t + \sum_{i=1}^{N} \gamma_i^* p_{i,t}^* + u_t, \tag{8}$$

where the γ_i^* denote the weights in the foreign price index. Clearly, the greater the disparity between the relevant national price indices, the greater the apparent disparity - represented by the term u_t - from aggregate PPP even when the LOP holds for individual goods. Note that, however, if the geometric price indices are homogeneous of degree one (i.e. an equiproportionate increase in all prices will raise the overall price level by the same proportion), then differences in weights across countries will matter less where price impulses affect all goods and services more or less homogeneously. An x percent increase in all prices in the foreign country will lead, for example, to an x percent increase in the foreign price level and the right hand side of (8) will be augmented by x and the change in the u_t term will be zero. Thus, assuming (without loss of generality) that domestic prices are constant, an x percent appreciation of the domestic currency is required in order to restore equilibrium.[9] In short, under the assumption that price impulses affect all goods and services more or less homogeneously, differences in baskets across countries will matter less. This assumption, while unrealistic in its exact formulation, appears quite plausible since shocks

[9] A similar analysis may be applied when some goods and services are nontradable. Suppose that the LOP applies only among traded goods. An x percent increase in all foreign traded goods prices implies, other things equal, an x percent appreciation of the domestic currency. But if there is also an x percent rise in all *nontradable* foreign goods prices, the PPP condition based on individual national price indices will also imply an x percent exchange rate movement.

to goods prices tend to have a strong common component that relates to costs of production and inputs, which tend to comove across both countries and goods.[10]

One of the key reasons why PPP exchange-rate calculations are still somewhat controversial is exactly because of the difficulties of finding comparable baskets of goods to measure purchasing power across countries. If two countries trade different baskets of goods, it is no longer logical to use the LOP to build PPP, since there is no strong reason why one should arrive exactly at the same price level by aggregating baskets of different goods. Moreover, people in different countries typically consume different baskets of goods, and the comparison of the cost of baskets of goods and services using a price index is further complicated because purchasing patterns and even the goods available for purchase differ across countries. For example, it would be desirable to make adjustments for differences in the quality of goods and services, which are hard to measure. All of these issues reflect in PPP disparities.

How severely do these issues limit the usefulness of PPP calculations as a guide to long-run exchange rate behavior? At the very least, they imply that PPP calculations cannot be exact, once one departs from the assumption of identical goods and identical baskets. However, there are several arguments to support the notion that the LOP and PPP continue to be useful as approximations to long-run exchange rate behavior. For example, with respect to the assumption of identical goods, it is clear that the theoretical construct of identical goods is not realistic when thinking about the LOP in practice, and that it is more sensible to think about similar goods. The notion of similar goods can be thought of as follows: goods are similar when they serve to satisfy the same consumption need; e.g. any car will satisfy the need to commute across two different locations. That specific need has an "intrinsic price", which is embedded in the wholesale and consumer price of the car in international markets. It is the intrinsic price that theoretically one would want to use when testing the LOP or PPP, but it is of course not observable. The total price will instead include a number of other factors, such as of course quality, size, etc., which differ across cars. Moreover, in different export markets, the very same car will also have different prices because of transactions and transport costs, tariffs and taxes, and because of other adaptations that affect demand and supply (e.g. the need to make cars with right-hand-side drive in Britain). The resulting price differentials are not necessarily violations of the LOP, and they are justifiable on grounds related to quality, brand, transaction costs etc. The wedge in prices that captures the deviation from the LOP (and hence PPP) will be bounded by the fact that similar goods are competing in international goods markets very much in the same way as identical goods do, with the main difference that, while competition for identical goods can only occur through prices, competition for similar goods occurs not only through prices but also through quality, for example. The price differentials that induce deviations from parity, however, are obviously bounded because of international competition: if the price of a good becomes too high relative to the price of a

[10] In practice, it is more common for national statistical bureaus to use arithmetic rather than geometric price indices, although deviations from PPP arising from this source are not likely to be large. Considerable differences may arise, however, where price impulses impinge heterogeneously across the various goods and services in an economy and, in particular, where price inflation differs between the tradable and nontradable goods sectors. A particular example of this is the Harrod-Balassa-Samuelson effect, which is discussed later.

similar good (e.g. the price differential exceeds massively what can be justified by the differential in quality), one would expect competition on prices to drive down the price differentials within a reasonable wedge.

Ultimately, however, the soundness of the above arguments is an empirical matter. In this sense, what matters is the empirical evidence from the literature on testing the LOP and PPP for different levels of aggregation in prices and different countries. This literature, as it will be clear at the end of this paper, indicates that the LOP and PPP tend to work reasonably well across a range of different goods and countries, which is indicative that the above arguments make empirical sense.

The choice of the appropriate price index to be used in implementing absolute PPP has been the object of a long debate in the literature, going back at least as far as Keynes (1923). All commonly used price measures include some proportion of nontradable goods, which may induce rejection of PPP. Thus, many attempts exist in the literature to construct appropriate price measures for testing PPP. An influential attempt in this context has been carried out by Summers and Heston (1991), who developed the "International Comparison Programme" (ICP) data set, which reports estimates of absolute PPP for a long sample period and a number of countries, using a common basket of goods across countries. The ICP is not, however, of great practical help in empirical work since it is constructed at infrequent and long time intervals and, for certain time periods, data are only available for a few countries. Moreover, extensive use of extrapolation has been made in order to solve this problem. Overall, therefore, price indices from official sources remain the basis commonly used for implementing absolute PPP, despite the discussed limitations. Another important development is the PPP spot rate calculated by the OECD, which is not based on indices but on actual prices, allowing the calculation of a direct measure of absolute PPP at annual frequency. We discuss these data and illustrate them later in this paper.

In general, however, the difficulty in finding evidence strongly supportive of PPP and the difficulties encountered in moving from the LOP to PPP has provided a strong motivation for researchers to investigate the LOP empirically using a variety of disaggregated data.

4 Empirical evidence on the LOP

4.1 Early tests of the LOP

In general, the early econometric studies suggest rejection of the LOP for a broad range of goods and provide empirical evidence both that deviations from the LOP are highly volatile and that the volatility of relative prices is considerably lower than the volatility of nominal exchange rates. This is suggested, for example, by two influential studies carried out in the 1970s. Isard (1977) uses disaggregated data for a number of traded goods (chemical products, paper and glass products among others) and for a number of countries, providing empirical evidence that the deviations from the LOP are large and persistent, and they appear to be highly correlated with exchange rate movements. Richardson (1978) finds very similar results to Isard, by using data for 4- and 7-digit

standard industrial classification (SIC) categories.[11]

Knetter (1989, 1993) uses high-quality disaggregated data (7-digit) and provides evidence that large and persistent price differentials exist for traded goods exported to multiple destinations (e.g. for German beer exported to the UK as compared to the US). Herguera (1994) investigates the implications of product differentiation for the price adjustment mechanism in international trade using an imperfect competition model. The models shows that market structure, product differentiation and strategic behavior can explain the persistent price differential of perfectly substitutable goods across countries (see also Chen and Knez, 1995; Dumas, Jennergren and Naslund, 1995). This is consistent with the "pricing to market" (PTM) theory of Krugman (1987) and Dornbusch (1987), whose main feature is that the same good can be given a different price in different countries when oligopolistic firms are supplying it.

4.2 The border effect

Parsley and Wei (1996) look for convergence towards the LOP in the absence of trade barriers or nominal exchange rate fluctuations by analyzing a panel of 51 prices from 48 cities in the US. They find convergence rates substantially higher than typically found in cross-country data, that convergence occurs faster for larger price differences and that rates of convergence are slower for cities further apart. Extending this line of research, Engel and Rogers (1996) use data for both US and Canadian cities and for 14 categories of consumer prices in order to analyze the properties of deviations from the LOP. The authors provide evidence that the distance between cities can explain a considerable amount of the price differential of similar goods in different cities of the same country. Nevertheless, the price differentials are considerably larger for two cities across different countries relative to two equidistant cities in the same country. The estimates of Engel and Rogers suggest that crossing the national border - the so-called "border effect" - increases the volatility of price differentials by the same order of magnitude which would be generated by the addition of 2,500 to 23,000 extra miles between the cities considered. Rogers and Jenkins (1995) find similar results to Engel and Rogers, providing evidence that the "border effect" is effective in increasing not only the volatility of price differentials but also their persistence.

Crucini, Telmer and Zachariadis (2005b) also show that the volatility of LOP deviations across goods is greater the farther apart are locations; see also Crucini and Shintani (2008) and Crucini, Shintani and Tsuruga (2009). The latter build a single-country, two-city model with nominal rigidities and transportation costs which predicts that volatility of LOP deviations is lower for goods with infrequent price adjustment after controlling for distance. They adapt the Engel and Rogers (1996) analysis to examine Japanese retail prices at the city level and find that the distance equivalent of nominal rigidities can be as large as the 'width' of the border documented in the literature on international LOP, casting doubt over interpretations of distance as a metric for market segmentation.

[11] Similarly, Giovannini (1988) uses data on domestic and dollar export prices of Japanese goods and provides evidence that deviations from the LOP - found to be large not only for sophisticated manufacturing goods but also for commodities such as screws, nuts and bolts - are mainly due to exchange rate movements.

4.3 Barriers to arbitrage and nonlinearities

Among the possible explanations of the violation of the LOP suggested by the literature, transport costs, tariffs and nontariff barriers play a dominant role. An estimate of the wedge driven by the costs of transportation is given, for example, by the International Monetary Fund: the difference between the value of world exports computed as "free on board" (FOB) and the value of world imports charged in full, or cost, insurance and freight (CIF) is estimated at about ten percent and is found to be highly variable across countries. Also, even if tariffs have been considerably reduced over time across major industrialized countries, nontariff barriers are still very significant. Governments of many countries often intervene in trade across borders using nontariff barriers in a way that they do not use within their borders (for example in the form of strict inspection requirements; see Knetter, 1994; Feenstra, 1995; Rogoff, 1996; Feenstra and Kendall, 1997).

Frictions in international arbitrage have important implications and, in particular, imply potential nonlinearities in the deviations from the LOP. The idea that there may be nonlinearities in goods arbitrage dates at least from Heckscher (1916), who suggested that there may be significant deviations from the LOP due to international transaction costs between spatially separated markets. A similar viewpoint can be discerned in the writings of Cassel (e.g. Cassel, 1922) and, to a greater or lesser extent, in other earlier writers (Officer, 1982). More recently, a number of authors have developed theoretical models of nonlinear real exchange rate adjustment arising from transaction costs in international arbitrage (e.g. Benninga and Protopapadakis, 1988; Dumas, 1992; Sercu, Uppal and Van Hulle, 1995; O'Connell and Wei, 2002). In most of these models, proportional or 'iceberg' transport costs ('iceberg' because a fraction of goods are presumed to 'melt' when shipped) create a band for the real exchange rate within which the marginal cost of arbitrage exceeds the marginal benefit. Assuming instantaneous goods arbitrage at the edges of the band then typically implies that the thresholds become reflecting barriers.

Some of these studies show that the thresholds should be interpreted more broadly than as simply reflecting shipping costs and trade barriers *per se*, but also as resulting from the sunk costs of international arbitrage and the resulting tendency for traders to wait for sufficiently large arbitrage opportunities to open up before entering the market (see in particular Dumas, 1992). O'Connell and Wei (2002) extend the iceberg model to allow for fixed as well as proportional costs of arbitrage. This results in a two-threshold model where the real exchange rate is reset by arbitrage to an upper or lower inner threshold whenever it hits the corresponding outer threshold. Intuitively, arbitrage will be heavy once it is profitable enough to outweigh the initial fixed cost, but will stop short of returning the real rate to the LOP level because of the proportional arbitrage costs.[12]

[12] Coleman (1995) suggests that the assumption of instantaneous trade should be replaced with the presumption that it takes time to ship goods. In this model, transport costs again create a band of no arbitrage for the real exchange rate, but the exchange rate can stray beyond the thresholds. Once beyond the upper or lower threshold, the real rate becomes increasingly mean reverting with the distance from the threshold. Within the transaction costs band, when no trade takes place, the process is divergent so that the exchange rate spends most of the time away from parity.

Some empirical evidence on the effect of transaction costs in this context is provided by Davutyan and Pippenger (1990). Subsequent recent studies modelling nonlinearities in the deviations from the LOP include Michael, Nobay and Peel (1994), Obstfeld and Taylor (1997), O'Connell (1998), Taylor (2001) and O'Connell and Wei (2002). In all these studies, the nonlinear nature of the adjustment process is investigated in terms of a TAR model (Tong, 1990). The TAR model allows for a transaction costs band within which no adjustment in deviations from the LOP takes place, while outside of the band as goods arbitrage becomes profitable the process switches abruptly to induce convergence towards the LOP. Michael, Nobay and Peel (1994) investigate the relative US dollar price of six wheat varieties and provide evidence for nonlinear mean reversion in deviations from the LOP. Obstfeld and Taylor (1997) employ disaggregated data (clothing, food and fuel) for 32 locations at a monthly frequency from 1980 to 1995, the US being the reference country. Their estimated thresholds are found to be between 7 and 10 percent on average across different types of goods. Obstfeld and Taylor (1997) discover transaction costs to be lower between the US and Asia (about 2 to 8 percent) than between the US and Europe (about 9 to 19 percent). Using two different sets of relative price panels over the period 1975 to 1992, O'Connell and Wei (2002) also find strong evidence of nonlinear mean reversion in deviations from the LOP.

Importantly, Taylor (2001) has shown that there can also be substantial upward bias in the estimated half life of adjustment from assuming linear adjustment when in fact the true adjustment process is nonlinear. This essentially invalidates studies that employ linear models to examine the validity of the LOP and the persistence properties of deviations from the LOP.[13]

Imbs, Mumtaz, Ravn and Rey (2003), confirm the presence of substantial nonlinearities in real exchange rate dynamics at the sectoral level. They maintain that there exists zones where arbitrage is not profitable because of transaction costs, rendering mean reversion inexistent. They subsequently compute the speed of mean reversion of sector-specific real exchange rates and relate them to economic determinants such as tradability and exchange rate volatility.

Studies are now cumulating evidence in favor of threshold-type nonlinearity in deviations from the LOP, but they are often based on few commodities or currencies.[14] However, Sarno, Taylor and Chowdhury (2004) provide a broad-based study on the presence of threshold-type nonlinearities in deviations from the LOP and on the ability of the TAR model to characterize them, using the latest available econometric technology in this context. In an attempt to contribute towards making TAR nonlinear dynamics in deviations from the LOP a stylized fact, they investigate the mean-reverting properties for real sectoral dollar exchange rates (deviations from the LOP) *vis-a-vis* five major currencies, for nine sectors since 1974. The results provide evidence suggesting that,

[13] Taylor (2001) also investigates the impact of temporal aggregation in the data. Using a model in which deviations from the LOP or PPP follow an AR(1) process at a higher frequency than that at which the data is sampled, Taylor shows analytically that the degree of upward bias in the estimated half life rises as the degree of temporal aggregation increases - i.e. as the length of time between observed data points increases. This time aggregation problem is a difficult issue for researchers to deal with since high-frequency data do not exist for prices.

[14] Also, most studies employing TAR models in this context were written before the publication of Hansen's (1996, 1997) work, which provides important econometric contributions for testing linearity against threshold-type nonlinearity and for estimating TAR models.

in general, the TAR model characterizes well deviations from the LOP across this broad range of currencies and sectors, yielding plausible estimates of transaction costs and convergence speeds.

It is worth noting that transaction costs differ widely across sectors in these results. Consider, for example, Germany, where estimated transaction costs for the paper products sector are found to be of the order of 1%, whereas estimated transaction costs for the food sector are some 20%. This implies that the US and German market for paper and paper products, printing and publishing is highly integrated, unlike the market for food, beverages and tobacco. The results also suggest that costs of arbitrage widely fluctuate across countries for a given sector. The paper sector in the UK reveals transaction costs of 19%, unlike the 1% for Germany. Relatively high costs of trade can be observed for the manufacturing sector and wood and wood product sector, in particular for the European countries, with transaction costs ranging from 17% to 20% and from 12% to 20% respectively, suggesting that US and European goods markets are less integrated for these sectors. It is interesting to note that transaction costs for the textile sector and for the food, beverages and tobacco sectors are relatively high for the European countries (from 14% to 20% for the latter, and from 11% to 20% for the former), while they are fairly low for Japan (from 6% to 7%).

Looking at the speed of adjustment parameters, these models suggest that adjustment towards the LOP is fairly fast (on average around 2 years once adjustment begins) although the estimated delay parameter, which measures the timing of the reaction of market participants to deviations from the LOP, is longer than one might perhaps expect. This means that deviations from the LOP may be somewhat sticky (given the delay parameter is on average larger than four quarters), but they are not particularly persistent.

Overall, these models suggest that deviations from the LOP become mean reverting only when they are large enough to generate profitable arbitrage opportunities net of transaction costs. These models, therefore, provide a rationale for threshold-type models of deviations from the LOP that allow for a jump from non-mean-reverting behavior within the transaction costs band to mean-reverting behavior outside the transaction costs band.

4.4 The tradable versus nontradable goods dichotomy

Engel (1999) measures the proportion of US real exchange rate movements that can be accounted for by movements in the relative prices of nontradable goods, at all possible horizons from one month up to 30 years. The study is performed with five different measures of nontradable goods prices and real exchange rates. The author reports that the relative prices of nontradable goods appear to account for almost none of the movement of US real exchange rates and considers the possibility of mismeasurement of traded goods prices.

Consistent with Engel (1999), Obstfeld and Rogoff (2000) find evidence of very slow mean reversion in shocks to the relative prices of tradables. It is suggested that it does not make much difference whether one uses tradables or nontradables to compute real exchange rates and hence that the properties of PPP deviations are largely the same regardless of the specific price index

used. These results hold across a broad set of currencies.[15]

At this point we should mention that there appears to be substantially stronger adjustment of prices to exchange rate changes at the importer level than at the consumer level. Goldberg and Knetter (1997) find that the pass-through of exchange rates to relative international prices is about 50% after one year, much faster than what we see in consumer price data. Thus, relatively large elasticities in international trade between exporters and importers can be consistent with exceedingly sluggish adjustment in the relative consumer price of tradables.

The relevance of the dichotomy between tradables and nontradables is, however, supported by other studies. For example, Imbs, Mumtaz, Ravn and Rey (2003) find a relationship between the speed of mean reversion of sector-specific real exchange rates and economic determinants such as tradability and exchange rate volatility. Along these lines, Crucini, Telmer and Zachariadis (2005) study the good-by-good dispersion in the absolute LOP deviations and report that much of this dispersion can be ascribed to how tradable the goods are, as well as to how tradable the inputs required to produce them are. Crucini and Shintani (2008) further stress that the classical tradable/nontradable dichotomy is relevant. They partition items into two categories and find that nontradable goods have more persistence than traded goods across different locations. An important conclusion emerging from this strand of the literature is, therefore, the positive relationship between the goods' tradability and the speed of adjustment towards the equilibrium price (the LOP).

4.5 The aggregation bias and micro price studies

Imbs, Mumtaz, Ravn and Rey (2005) suggest that since sectoral real exchange rates might revert to the mean with different speeds, this heterogeneity could give rise to highly persistent aggregate series while relative price persistence is low on average at a disaggregated level. The authors maintain that the aggregate real exchange rate is persistent because its components have heterogeneous dynamics that standard time series and panel methods fail to control for. They argue that when this heterogeneity is taken into account, the estimated persistence of real exchange rates falls dramatically (its half-life, for instance, falls to around one year).

Chen and Engel (2005) question Imbs, Mumtaz, Ravn and Rey (2005), citing Engel's (2000) paper which concludes that "for most categories of goods, there is not even evidence that deviations from the LOP tend to be eliminated." In this line are the findings of Rogers and Jenkins (1995) and Crucini and Shintani (2002) who explicitly find no aggregation bias. This point is given further support more formally by Gadea and Mayoral (2009), who discard the notion that there is an aggregation bias in estimates of the persistence of PPP deviations both theoretically and empirically.

[15] However, the traded/nontradable goods distinction is a bit ambiguous at the retail level since many traded goods embody large nontradable components which makes the dichotomy arbitrary. Nevertheless, the results are somewhat surprising and cannot be attributed solely to price aggregation problems, as many researchers report similar findings even for highly disaggregated data on goods that are perceived as highly tradable (e.g. Engel and Rogers, 1996).

A separate literature, including contributions by Crucini and Telmer (2007) and Nakamura (2008), however, shows substantially more volatility in LOP deviations than PPP deviations, implying that shocks to individual goods mostly average out in the aggregation to PPP. In other words, aggregation increases persistence and reduces variability.[16]

4.6 Adjustment through prices or exchange rates?

The LOP and PPP simply state that in the long-run the exchange rate equals the relative price of similar goods or baskets of goods respectively. Although they are propositions about the long-run behavior of exchange rates rather than of prices, they do not specify how adjustment takes place and, specifically, whether adjustment takes place solely via exchange rates or also via prices.

While, surprisingly, there is no empirical evidence on this question for the case of the LOP to the best of our knowledge, some evidence exists for PPP calculated using the CPI. For example, Goldfajin and Valdes (1999) and Cheung, Lai and Bergman (2004) find that the nominal exchange rate is responsible for most of the adjustment towards PPP, rather than prices. However, prices also contribute to the reversion to PPP, although their role is less important than exchange rates quantitatively. Sarno and Valente (2006) confirm this finding in a model for a century of data across different exchange rate regimes but provide an important refinement: adjustment to long-run equilibrium takes different forms in fixed versus floating exchange rate regimes. During fixed regimes, prices bear the burden of adjustment to PPP; however, even in fixed regimes exchange rates can contribute since devaluations generally appear to be designed to correct misalignments with respect to the PPP equilibrium.

Overall, the existing evidence indicates that the primary role in adjusting to PPP is taken by exchange rates rather than prices, although both exchange rates and prices respond to deviations from parity.

5 Further discussion

5.1 Transitory and structural disparities from parity

Over short periods, nominal exchange rates move substantially and prices do not, so real and nominal exchange rate volatilities in the short term are correlated almost one for one, and the LOP for traded goods is often violated (Flood and Rose, 1995). This pattern holds over a wide swathe of historical experience (Taylor, 2002).

As Crucini, Telmer and Zachariadis (2005) indicate, a substantial part of empirical and theoretical work in international economics endeavours to answer two questions: what determines whether a deviation from the LOP will be large or small, and what determines whether a deviation from the

[16] A final issue which is worth noting is the possibility that the failure of the LOP may be explained by institutional factors typical of this century which have increased the persistence of deviations from the LOP. Nevertheless, Froot, Kim and Rogoff (1995), using data on prices for grains and other dairy goods in England and Holland for a span of data which goes from the fourteenth to the twentieth century, provide empirical evidence suggesting that the volatility of the LOP is quite stable during the whole period, regardless of the many regime shifts during the sample.

LOP will be enduring or short-lived. The empirical literature on the first question is very limited due to paucity of absolute price data on comparable goods across international locations. The theoretical literature, however, provides some answers, including the models of Dumas (1992) and Sercu, Uppal and van Hulle (1995), which emphasize the magnitude of shipping costs in consumption goods and physical capital. Furthermore, the models of Krugman (1987) emphasize imperfect competition, while the models of Balassa (1964) and Samuelson (1964) emphasize productivity differences across traded and nontradable goods. Finally, the models of Ethier (1979) and Jones and Sanyal (1982) emphasize that much of international trade takes place in intermediate inputs, not final goods and services. In every case, the first-order restrictions from theory are on absolute LOP deviations.

Overall, it seems rather implausible that the high volatility and strong persistence of PPP deviations could be completely attributed to real factors. As volatilities are also found to systematically differ across monetary regimes, it is likely that some combination of nominal shocks and price stickiness might be affecting the short-run volatility of exchange rates. As Obstfeld (2001), Obstfeld and Rogoff (2001) and Burstein and Neves and Rebelo (2003) note, it could be that economies are more closed than originally thought, since large sectors are nontradable. In this way, in an economy with price stickiness and a nontradable sector, small monetary shocks can generate high levels of exchange rate volatility (Burstein, Eichenbaum and Rebelo, 2005). As soon as the nontradable share of the economy increases, the economy becomes less "open" and the LOP applies to a smaller fraction of goods, allowing a larger role for exchange rate overshooting and other sources of exchange rate volatility (Obstfeld and Rogoff, 2000; Hau, 2000, 2002).

Furthermore, the PPP hypothesis is based on the concept that the real exchange rate equilibrium remains fixed forever, which is not necessarily true. Several theories that have tried to rationalize the changes in the level of the real exchange rate focus on the net international asset position. Lane and Milesi-Ferretti (2002) find some empirical evidence supporting this argument. They report that countries with larger positive net asset positions tend to have more negative trade balances and stronger real exchange rates, controlling for other factors and allowing for real return differentials across countries. This finding suggests that if the equilibrium PPP exchange rate changes following net wealth changes and if these shifts are not controlled for in a model, then the exchange rate will seem to deviate from what is falsely assumed to be a fixed PPP rate for too much or for too long.

The other key theory for changing real exchange rate equilibria is built around the notion of nontradable goods. The Harrod-Balassa-Samuelson (HBS) model of equilibrium real exchange rates has recently experienced a revival. In this model, countries are thought to generate wealth by fostering productivity in traded sectors. In the meanwhile, all nontradable sectors, in rich and poor countries, remain in technological lethargy. Suppose the LOP holds among traded goods and labor is mobile among sectors, but not internationally. As productivity in the traded sector rises, wage levels rise, so prices of nontradable goods will have to rise too. Should one measure the overall price index as a weighted average of tradable and nontradable goods prices, relatively rich countries will tend to have stronger currencies.

Although early studies of the HBS effect found little support in the data from the 1950s to the early 1970s (Officer, 1982), recent research studying later periods has often found support for this hypothesis (Micossi and Milesi-Ferretti, 1994; De Gregorio, Giovannini and Wolf, 1994; Chinn, 2000). This potentially reveals developments in the PPP literature in a broader sense: longer spans of data and wider country samples, along with more powerful econometric techniques, have helped to make the relationship tighter. Furthermore, up to date findings hint that the magnitude of the HBS effect has been variable over time—definitely during the postwar period and possibly going back several centuries (Bergin, Glick and Taylor, 2004). A reason could be that the nontradable share has risen over time; however, this effect does not match the changes that have occurred in terms of magnitude, nor the timing of the changes. Another possible explanation is that the productivity advances of tradable and nontradable goods have been different across time. Bergin, Glick and Taylor (2004) develop the hypothesis that trade costs determine tradability patterns, an assumption which allows various productivity shocks to give rise eventually to an endogenous HBS effect. Overall, if the equilibrium exchange rate is moving gradually over time, and our statistical analysis presupposes that the PPP exchange rate is fixed over time, then estimates of the speed of reversion to PPP will be biased. Indeed, allowing for long-run trends in the real exchange rate could be of great importance in understanding PPP deviations. Along these lines, Taylor (2002), reports relatively low half-lives in a 20-country panel when allowance is made for long-run trends in the equilibrium exchange rate. Allowing for nonlinear time trends, Lothian and Taylor (2000) suggest that the half-life of deviations from PPP for the dollar-pound exchange rate may be as low as 2 years. Lothian and Taylor (2008) show that the HBS effect may account for about a third of the variation in this real exchange rate.

Summing up, the equilibrium real exchange rate might trend over the long run due to these wealth effects, productivity effects and other forces as potential triggers. However, there is substantial uncertainty on the economic importance of HBS effects, which appear to change over time in ways that economists do not fully understand. Hence, our reading suggests that, as a first approximation to the long-run behavior of the real exchange rate, PPP is empirically validated, regardless of the precise basket of goods and services examined and of the proportion of nontradables included in price indices.[17]

5.2 Aggregating from the LOP and PPP: what can we infer?

For our purposes, we are interested in understanding what happens empirically to the properties of the LOP as we aggregate from individual tradable goods and services to sectors, and then to all

[17] A more *ad hoc* formulation that incorporates changing real exchange rate equilibria is the fundamental equilibrium exchange rate (FEER), which comes in a number of different variants. However, in essence this is a framework that is based on the idea that, especially for emerging countries undergoing major structural change, the real exchange rate equilibrium shifts over time due to HBS effects, terms of trade shocks, and the process of opening up to international trade that typically accompanies the transition of emerging markets to developed markets. Even in these models, typically the uncertainty in parameter estimation is such that it is difficult to make accurate inference on whether a currency is misaligned unless the misalignment is very large, in which case the disparity would be apparent even using PPP rather than a larger model of real exchange rate determination.

tradables, and finally to all goods (tradables and nontradables). The reading of the literature on the LOP applied to individual goods and individual sectors indicates that the LOP holds in the long-run. To the extent that the LOP holds for individual goods, it ought to hold for sectors of similar tradable goods. Then, if the LOP holds for each sector of tradable goods, it ought hold for all tradable goods, i.e. the PPP hypothesis for tradable goods *must* hold, given that the LOP holds for individual goods.

Moving one further level up in the aggregation process, and therefore assessing PPP applied to national (e.g. consumer) price indices as opposed to baskets of tradable goods only, is less straightforward from a theoretical standpoint. The inability to extend the arguments about arbitrage in goods markets to nontradable goods and the potential presence of HBS effects does not allow us to infer that PPP must also hold for national price indices. However, we also know from the extensive literature on PPP and on HBS effects that (i) PPP holds in the long-run across a number of currencies even when using price indices that include nontradables and, consistent with this, (ii) HBS effects are generally small, albeit varying over time. It is not entirely clear why PPP holds for consumer price indices, given that they include nontradables. Clearly, because of the lack of arbitrage opportunities among nontradables, the mechanism that keeps price levels close to each other across countries cannot be due to the arbitrage forces that underlie the commodity-arbitrage view of the LOP. Cassell's (1922) influential thinking on PPP was that this hypothesis relates to broad price indices and a currency's value. The empirical fact that PPP provides a good first approximation to the long-run behavior of real exchange rates constructed with national price indices lends some support to Cassell's view at this high level of aggregation. At the same time, the argument that catching up in terms of technological innovation and growth across countries mitigates HBS effects is also a likely part of the explanation for this result. While it is not possible to exactly identify the reasons why PPP should hold when applied to both tradables and nontradables, however, there is plenty of evidence that it does hold.

Overall, the above logic and the empirical evidence available to us further indicates that the LOP and PPP provide useful guidance to the long-run behavior of exchange rates. However, it seems plausible that the persistence of deviations from parity will be higher when one moves from the LOP and PPP for tradable goods to variants of PPP that include nontradables. Hence the choice of the price index used in PPP calculations should in principle have implications for the strength with which PPP holds; for example, PPP deviations obtained using the GDP deflator and the CPI should be more persistent than PPI-based real exchange rates, and in turn more persistent than deviations from PPP for tradable goods only. How relevant is this issue empirically?

5.3 An eyeball analysis of PPP

At this point, it is instructive to illustrate the above claims by eyeballing some data on deviations from PPP for a variety of cases. Let us start from Figure 1, which plots the time series for the dollar-sterling real exchange rate over the sample period from 1791 to 2010. The data are an updated version of the annual data set used by Lothian and Taylor (1996), using the wholesale

price index; we plot the log-real exchange rate in deviation from its mean, so that PPP is obtained when the rate is equal to zero. First, it is interesting how this real exchange rate appears to have a tendency to return to its long-run mean, i.e. the PPP equilibrium, although the mean is crossed only 22 times in 210 years of data, indicating a remarkable degree of persistence. Second, the time series suggests that the misalignments have been as large as 40 percent (both above and below PPP), suggesting that deviations from PPP have been very large indeed at some points in time. Third, the real exchange rate appears to be more persistent when it is in the proximity of the long-run mean, whereas reversion towards the mean happens more rapidly when the absolute size of the PPP deviation is large, providing visual support for the evidence of nonlinear adjustment discussed earlier. Overall, this eyeball analysis of 210 years of real dollar-sterling illustrates some of the key basic points arising from our reading of the PPP literature: deviations from PPP are stationary, albeit persistent, and are very persistent in the neighborhood of PPP, while being mean-reverting at a faster speed when the deviation from PPP gets larger. Again, this is consistent with the existence of nonlinear dynamics in the real exchange rate, implying that the speed of mean reversion is state dependent.

We now turn to the behavior of the real exchange rate for monthly data over the dollar floating era. Figures 2-4 show the real exchange rates (again in log-deviations from the mean) for the US dollar against the UK pound and Japanese yen since 1973, and the Deutsche mark-euro since the German unification in 1991, when PPI data for Germany become available. In each graph, we plot three real exchange rates, obtained using three different price indices: CPI (blue line), GDP deflator (red line), and PPI (green line). The graphs confirm the earlier eyeball analysis, but they also illustrate further points. First, the estimate of the PPP equilibrium is made cumbersome in shorter samples because both of the difficulty to estimate the mean accurately and because of the stronger effect of the choice of a base year. This is especially apparent if one compares Figures 1 and 2, since in the former the pound sterling looks likely to be undervalued in the last couple of years, whereas the latter suggests the pound looks likely to be overvalued. Second, the tendency to revert to PPP appears less strong when looking at shorter samples, consistent with the well-known difficulties of the empirical literature to detect PPP during the post-Bretton Woods period. Third, real exchange rates constructed using different price data are highly correlated and display very similar properties, because the volatility of the deviations from PPP (for both tradables and nontradables) is largely driven by the volatility of the nominal exchange rate rather than relative prices. This is consistent with the claims by Engel (1999) and Obstfeld and Rogoff (2000). Nevertheless, earlier we argued that PPI-based real exchange rates are more appropriate than CPI- and GDP-based real exchange rates, due to the lower proportion of tradables included in the PPI. While this is not clear from Figure 2, a simple calculation illustrates this point. Specifically, if PPI-based real exchange rates are indeed closer to PPP, the cumulative real exchange rate Σq_t must be closer to zero than the other measures.[18] The table below makes it clear that this is indeed the case for the pound and the euro; for the yen the PPI-based real exchange rate only

[18] Adjustment towards PPP should also be faster, and indeed we find that this is the case, but for the purpose of this discussion we shall focus on the cumulative deviation from PPP rather than the adjustment to equilibrium.

has the second smallest cumulative real exchange rate but all of the three values are actually very small:

	GDP	PPI	CPI
Japan	0.00	1.14	-2.76
UK	-14.32	-13.24	-17.21
DM-Euro	3.87	0.00	8.10

One problem with the data used generally in LOP and PPP analyses is that they are based on imperfect price indices. In fact, one of the dilemmas of using PPP in practice is which PPP measure to use. A direct approach would use the actual price levels of some combination of goods and services and compare these across countries to arrive at an actual level of PPP (such as the Big Mac Index). This is in principle preferable to price indices, such as the CPI or PPI, because PPP levels would not need to be derived by assuming some earlier base period that represents the PPP equilibrium. In some sense, while the use of price indices allows one to pick a price index that contains more or less tradable goods, there is scope for data-mining by choosing the base period that results in PPP working best. For this reason, it is very useful to look at, as an alternative, a direct approach and use the OECD's PPP values (OECD, 2006). The OECD calculates direct PPP values in order to make international GDP comparisons, rather than as a tool to forecast currencies. Therefore, it may be seen as more robust and comprehensive than other direct PPP measures.[19]

We retrieve from the OECD the spot exchange PPP value, which is the nominal exchange rate that is needed for PPP to hold, using their direct measures of prices at the annual frequency. The PPPs calculated by the OECD are still price relatives whether they refer to a product group or to an aggregate. It is just that in moving up the levels of aggregation the price relatives refer to increasingly complex assortments of goods and services. Thus, for example, if the PPP for GDP between Germany and the US is 0.97 euros to the dollar, it means that 0.97 euros has to be spent in Germany to obtain the same volume of final goods and services that one dollar purchases in the US. Note that this does not imply that the baskets of goods and services purchased in both countries will be identical. The composition of the baskets will vary between countries reflecting their economic, social and cultural differences, but both baskets will, in principle, provide equivalent satisfaction or utility.

We calculate the difference between the observed nominal exchange rate and the spot PPP value, which is essentially a direct measure of the deviation from absolute PPP. Figure 5 plots this measure of the deviation from PPP (i.e. the real exchange rate), again for the US dollar against the UK pound, Japanese yen and the Deutsche mark-euro since the collapse of the Bretton Woods system in 1973. Under this measure, PPP is obtained when the real exchange rate equals unity.

[19] It is worth noting that some currency managers prefer to use the OECD PPP data exactly for the reasons outlined above. A notable example is Deutsche Bank (2007), whose *FX Value Index* is traded exactly using these OECD PPP data. The index calculates deviations from PPP in the same way as discussed in this section and, in order to take into account the importance of nonlinearities, it trades only in the most misaligned currencies.

These graphs illustrate several important points. First, when using a direct measure of absolute PPP, the pound sterling appears to be grossly undervalued at the beginning of the post-Bretton Woods period, the yen slightly undervalued, and the Deutsche mark roughly at PPP. At the end of the sample in 2010, however, the pound sterling and the euro appear very close to PPP, while the yen appears somewhat overvalued. Second, the real exchange rates constructed with OECD direct price measures appear to have the same properties as the real exchange rates obtained using conventional price indices, in the sense that they are persistent and quite volatile, although volatility is difficult to compare given that the OECD data are at annual frequency. However, the persistence does not appear as extreme as in standard aggregate measures of the real exchange rate, and over the 37-year period of this sample there seems to be a clear tendency towards PPP (unity). Formal unit root tests indicate that these real exchange rates are indeed clearly stationary - i.e. they converge to their PPP value in the long-run - with high statistical confidence.[20] Also, estimation of regressions designed to understand whether the adjustment to PPP occurs through relative prices or exchange rates indicates that virtually all of the adjustment to PPP occurs via exchange rates, which respond very strongly to past PPP misalignments.

These properties indicate that there is indeed a long-run comovement between nominal exchange rates and relative prices, which we can observe quite clearly in the data. Figures 6-8 show, for each of the three exchange rates, the graph of the nominal exchange rate and the relative price provided by the OECD. The graphs make apparent how, while the nominal exchange rate is a lot more volatile than relative prices, exchange rates and prices appear to share the same long-run trend throughout the post-Bretton Woods period. This is exactly what one would expect: the nominal exchange rate moves in the short-run in response to a large number of factors, some of which possibly unrelated to economic fundamentals, but over long periods of time there appears to be a remarkable degree of convergence towards PPP. Put another way, while it may be difficult to produce a long-horizon forecast of the nominal exchange rate or relative prices in isolation, this evidence suggests that PPP is a reasonable assumption for long-horizon forecasting of the real exchange rate.

5.4 Emerging markets

5.4.1 Nonlinear Evidence on PPP

While the bulk of econometric studies regarding the validity of PPP and LOP focus on major currencies, it is useful to list the work that has been carried out on the nonlinear behavior of emerging market currencies. Along these lines, Sarno (2000), by extending the work by Bahmani-Oskooee (1998) on testing long-run PPP for a set of Middle Eastern countries during the post-Bretton Woods period, finds strong support for nonlinear reversion of real exchange rates towards

[20] For example, we carried out the panel unit root test of Im, Pesaran and Shin (2003) for the null hypothesis of a unit root (PPP not valid) against the alternative hypothesis that each of the real exchange rate series is stationary (PPP valid for all currencies). We also applied a multivariate Augmented Dickey-Fuller test for the same null hypothesis. The null hypothesis was rejected with 99 percent confidence under both test statistics, lending strong support to long-run PPP for these exchange rates.

a stable equilibrium for each country examined.

Several papers target the Asian region. Liew, Chong and Lim (2003) reject a linear model in favor of a nonlinear model for the real exchange rate of 11 Asian economies which shows convergence to PPP. Also, Liew, Baharumshah and Chong (2004a), by applying nonlinear methods to a set of Asian real exchange rates, confirm long-run PPP for 8 US dollar-based and 6 Japanese yen-based rates. Liew, Baharumshah and Lau (2004b) document that both the bilateral Indonesian rupiah-US dollar and Singaporean dollar-US dollar adjust nonlinearly towards the PPP equilibrium level, while Liew (2004) suggests that the real exchange rates of Indonesia, Philippines, Singapore and Thailand exhibit nonlinear mean reversion to PPP, with asymmetric responses to overvaluations and undervaluations.

Anoruo, Liew and Elike (2006) validate the long-run PPP hypothesis in the African region by demonstrating that 11 African real exchange rates conform to PPP with a nonlinear mean-reverting process. Finally, Cerrato and Sarantis (2006) provide evidence on nonlinear mean reversion in the real exchange rates of a number of developing and emerging market economies, using recently developed nonlinear methods and a unique set of monthly data on black market exchange rates.

5.4.2 Nonlinear Evidence on the LOP

Studies on the LOP nonlinear dynamics in emerging markets include Fan and Wei (2006), who study price convergence of the LOP in China and find strong evidence in support of convergence towards the LOP in Chinese domestic markets. However, this study obviously cannot say anything about exchange rate risk.

Nevertheless, Blavy and Juvenal (2009) report strong evidence of nonlinear convergence to the LOP across Mexico, Canada, and the US in both the pre-NAFTA and post-NAFTA periods, but post-NAFTA adjustment is faster. Overall, their study suggests that although emerging markets may face higher transaction costs than developed countries, trade liberalization potentially helps in lowering relative price differentials between countries. Since mean reversion occurs when deviations from the LOP are significant and the benefits of arbitrage are higher than transaction costs, emerging markets are expected to display lower speed of adjustment compared to major industrialized markets.

6 Conclusion and implications

This paper has surveyed the empirical evidence on the properties of deviations from the LOP and PPP for tradable goods. While it is fair to say that a universal consensus may not exist yet, the emerging consensus at the present time is converging towards the view that deviations from the LOP are transitory and therefore the LOP holds in the long-run among a broad range of tradable goods and currencies.

In our view, a promising strand of research which goes some way towards understanding the behavior of LOP deviations is the literature that has investigated the role of nonlinearities in the

adjustment towards the long-run equilibrium implied by the LOP (e.g. Obstfeld and Taylor, 1997; Sarno, Taylor and Chowdhury, 2004; Blavy and Juvenal, 2009). For example, Sarno, Taylor and Chowdhury (2004) provide evidence of nonlinear reversion towards the LOP in a number of major sectoral exchange rates during the post Bretton Woods period. However, they also provide evidence of price stickiness and heterogeneity across goods and currencies, as one would expect.

While it would be overly simplistic to believe that all that drives exchange rates is goods prices, the empirical evidence surveyed here suggests that the LOP is at least a good first approximation to the link between exchange rates and goods prices across countries. Put another way, if price differentials of individual goods do not converge to the same number over time (once expressed in the same currency), the drift must be small enough to be statistically and economically insignificant. We also examined some direct measures of absolute PPP using data from the OECD and illustrates that such direct measures lend clear support to PPP as a valid international parity condition.

In terms of implications for a long-horizon investor that holds a diversified international portfolio of equities and bonds, it seems clear that there is little need to hedge exchange rate risk. If PPP holds for baskets of tradable goods, long-term returns from diversified portfolios are largely unaffected by exchange rate risk.

Of course, this does not mean that a long-term investor is not advised to invest in currency markets. It simply means that any choice to invest in currency markets is or should be guided by the desire to obtain a risk premium different from that generated by e.g. equities or bonds. It is well known ever since Fama (1984) that there is a risk premium in foreign exchange due to the fact that high-interest currencies tend to appreciate over time, or at least not to depreciate enough to offset interest rate differentials (Burnside *et al.* 2011; Menkhoff *et al.*, 2011). This is also confirmed in broader analyses of portfolios of long-term investors who wish to minimize risk (e.g. Campbell, Serfaty-de Medeiros and Viceira, 2010). However, hedging currency risk for an investor whose horizon is essentially eternity seems unwise and indeed unnecessary.

A Appendix: Sample and data coverage for LOP studies

In Table 1 we report the estimated transaction costs for sectoral real exchange rates across five dollar exchange rates and nine sectors, as reported by Sarno, Taylor and Chowdhury (2004) using a TAR model with 8 lags. The following acronyms are used: basis metal industries (BMI), chemicals and chemical petroleum, coal, rubber and plastic products (CHE), food, beverages and tobacco (FOD), manufacturing goods (MAN), electrical goods (MEL), fabricated metal products, machinery and equipment (MEQ), paper and paper products, printing and publishing (PAP), textile, wearing apparel and leather industries (TEX), and wood and wood products, including furniture (WOD).

Table 1. The threshold magnitude across countries and sectors

	BMI	CHE	MEL	MEQ	FOD	MAN	PAP	TEX	WOD
UK	0.10	0.17	0.03	0.13	0.11	0.19	0.19	0.20	0.14
France	0.04	0.19	0.17	0.18	0.13	0.19	0.05	0.14	0.12
Germany	0.07	0.17	0.07	0.08	0.20	0.17	0.01	0.19	0.18
Italy	0.04	0.02	0.18	0.20	0.20	0.20	0.16	0.19	0.20
Japan	0.04	0.05	N/A	0.17	0.07	0.14	0.05	0.06	N/A

In Table 2, we report the full set of cities and countries studied by Obstfeld and Taylor (1997). The full set of indices available covers clothing, food, fuel, health, household, equipment, housing, recreation, transportation, and a basket of all consumer goods.

Table 2. List of 32 city and country locations under examination.

U.S.	Vancouver	Germany	Switzerland
Chicago	Winnipeg	Greece	UK
Los Angeles	Mexico	Italy	Hong Kong
New York	Austria	Netherlands	Japan
Philadelphia	Belgium	Norway	Singapore
Canada	Denmark	Portugal	Taiwan
Ottawa	Finland	Spain	New Zealand
Toronto	France	Sweden	South Africa

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Figure 1: Logarithm of GBP/USD Real Exchange Rate, 1791-2010

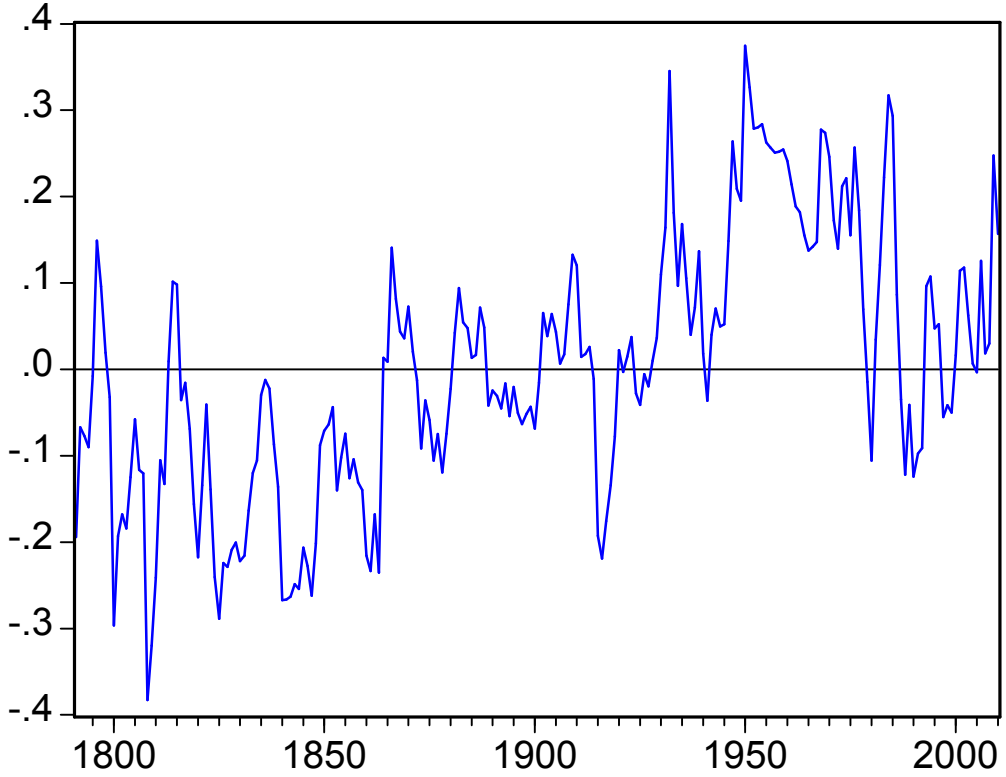

Figure 2: GBP/USD: Real Exchange Rates Calculated Using Different Price Indices (1973-2010)

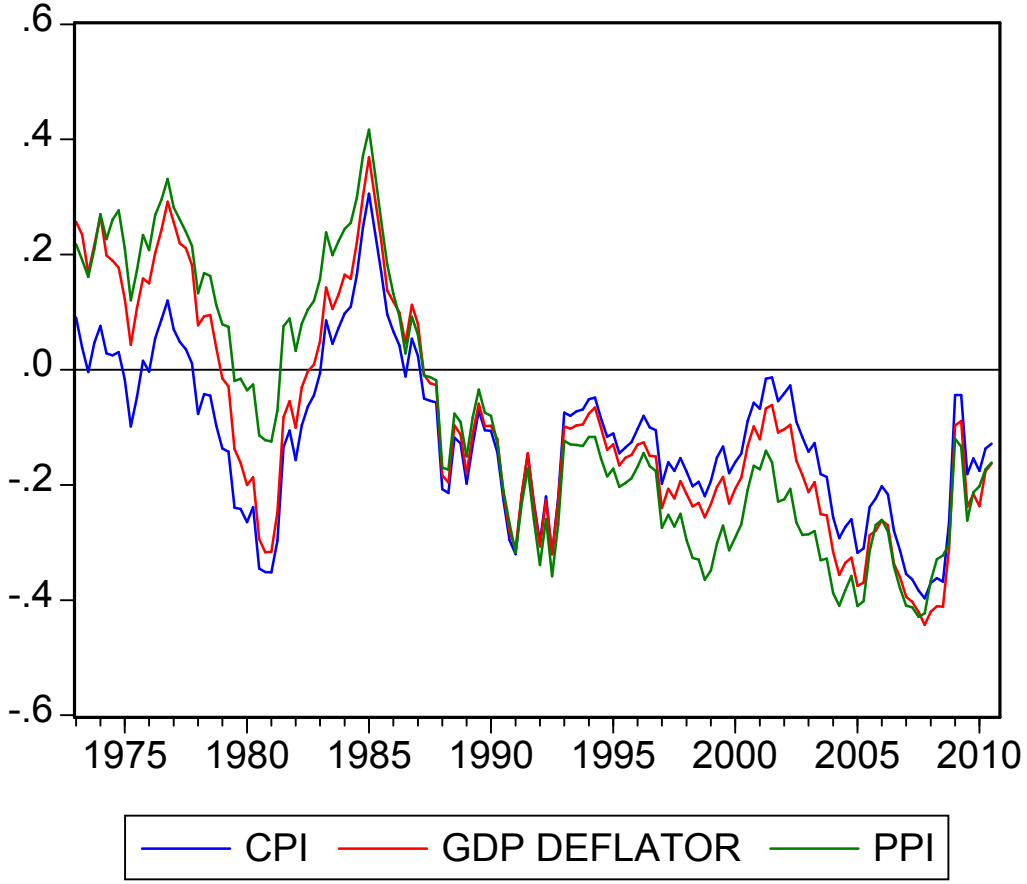

Figure 3: JPY/USD: Real Exchange Rates Calculated Using Different Price Indices (1973-2010)

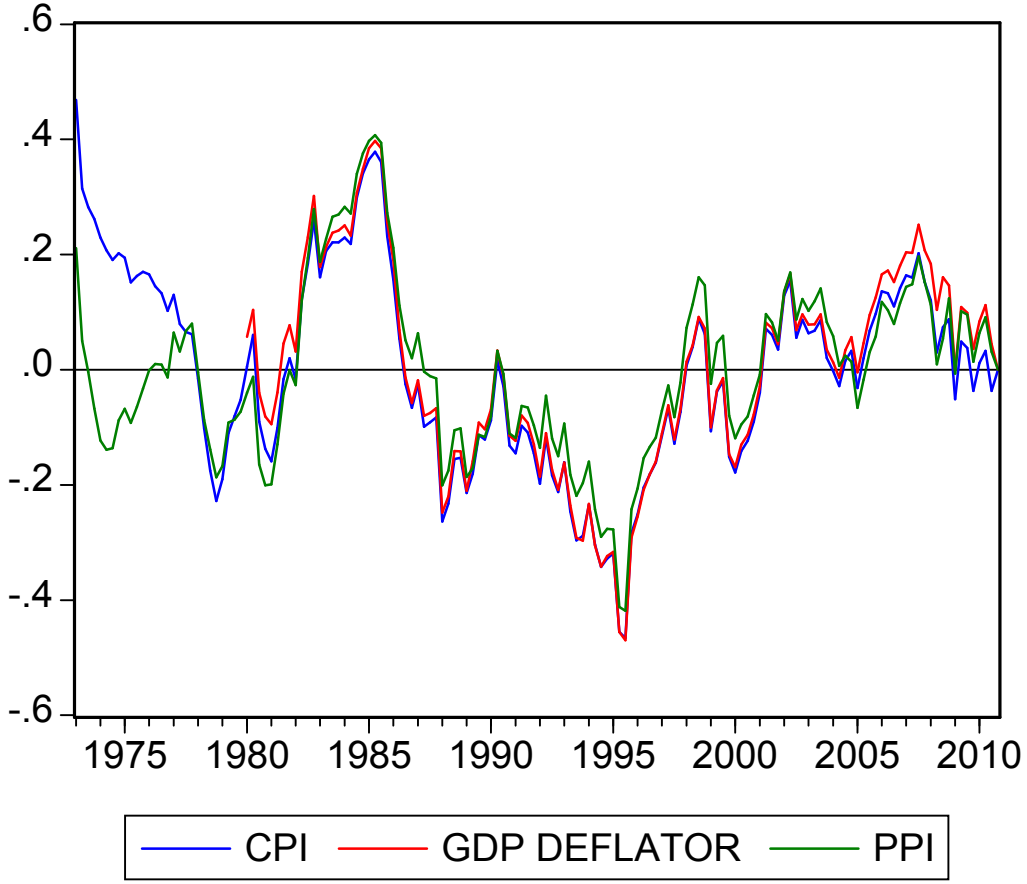

Figure 4: DEM-EUR/USD: Real Exchange Rates Calculated Using Different Price Indices (1991-2010)

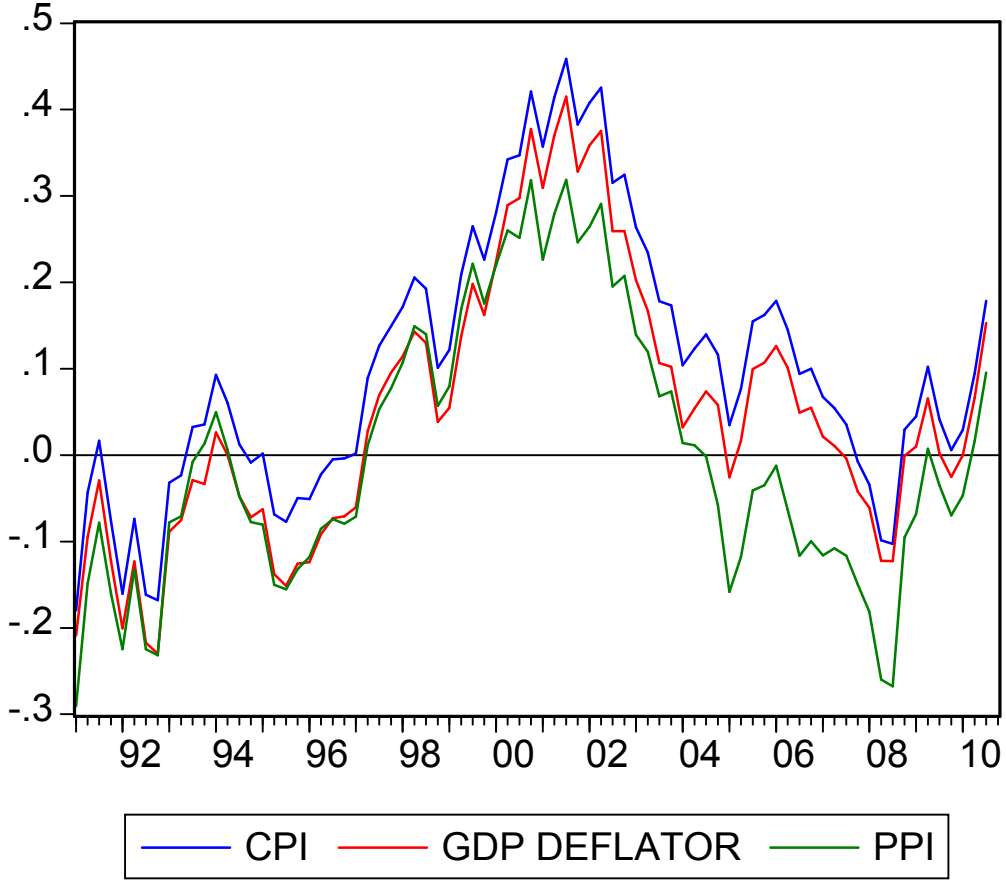

Figure 5. Real Exchange Rates against the USD (1973-2010)

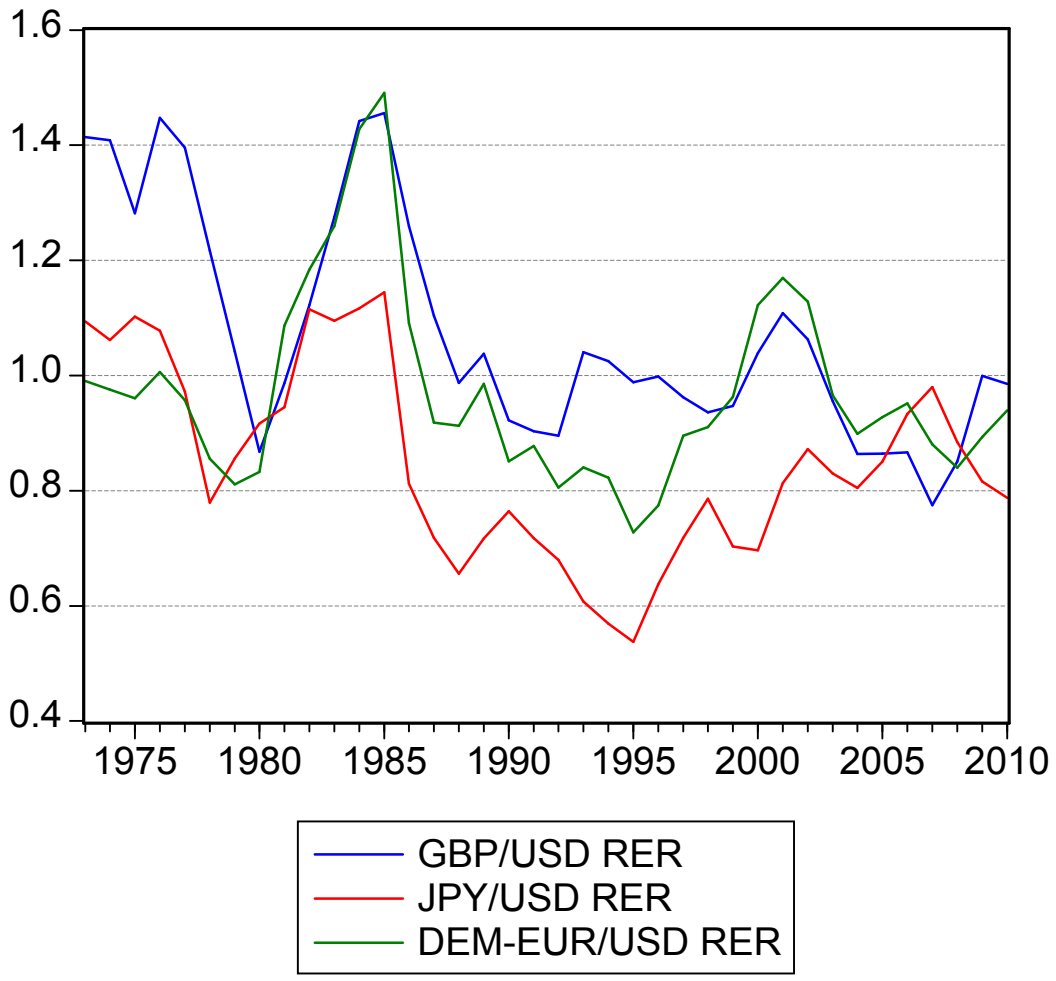

Figure 6: GBP/USD Nominal Exchange Rate versus
GBP/USD PPP Spot Rate (OECD Data), 1973-2010

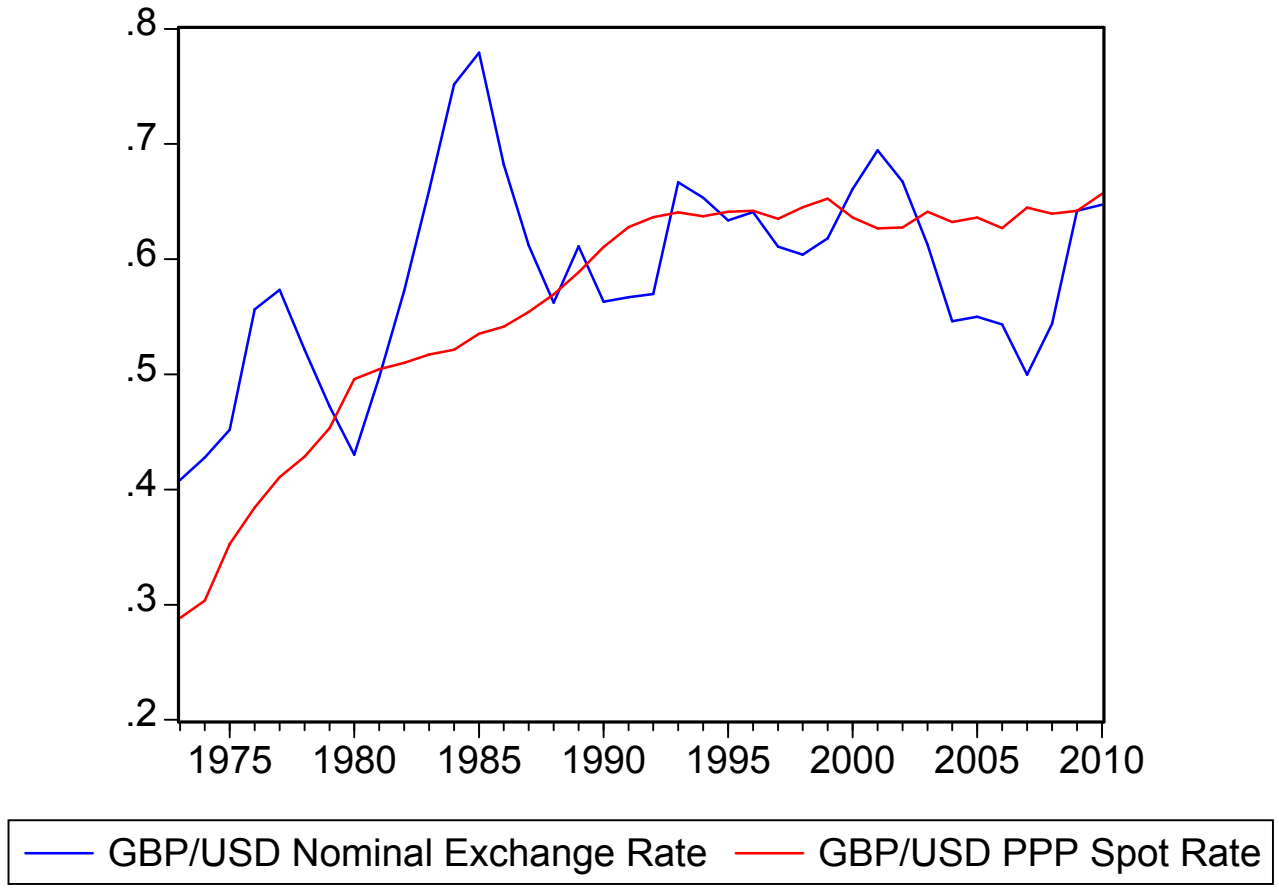

Figure 7: JPY/USD Nominal Exchange Rate versus
JPY/USD PPP Spot Rate (OECD Data), 1973-2010

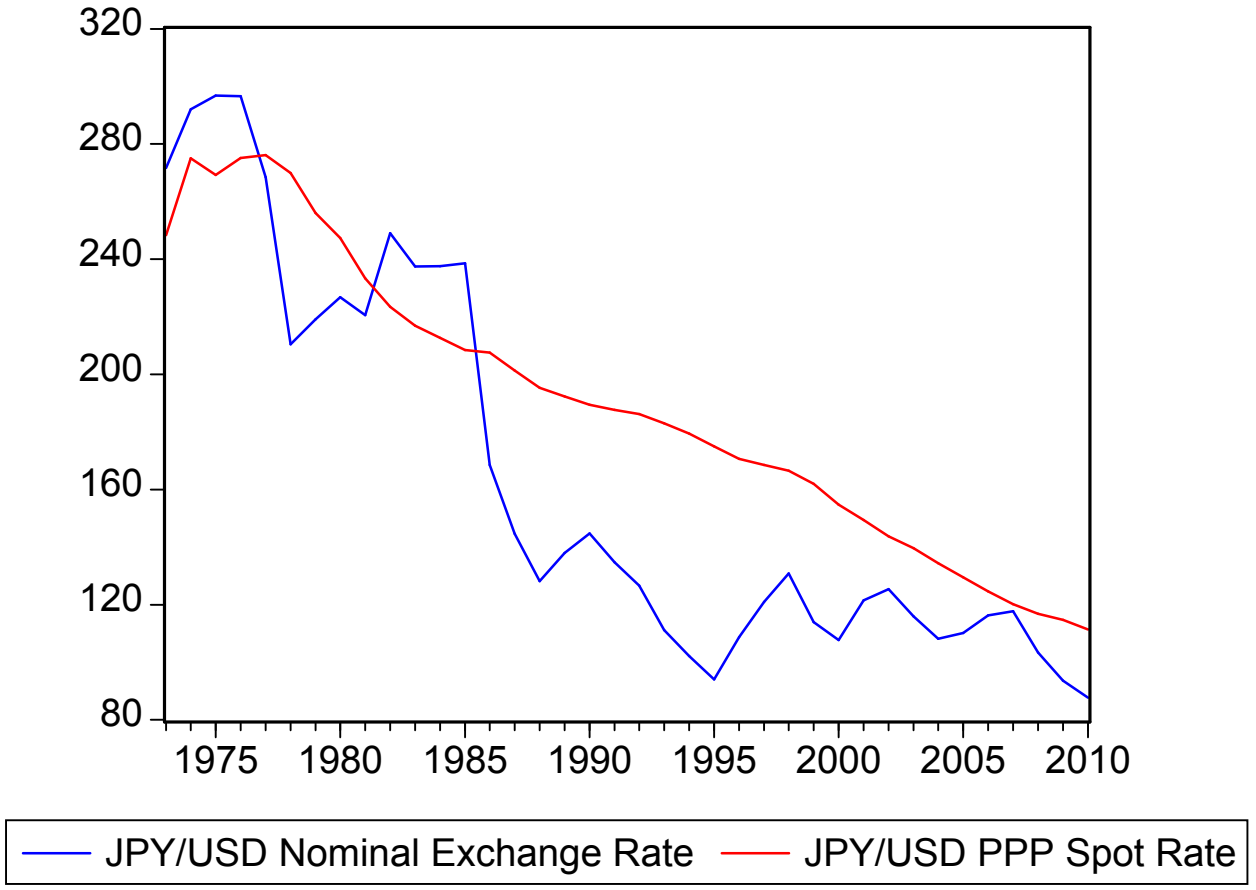

Figure 8: DEM-EUR/USD Nominal Exchange Rate versus DEM-EUR/USD PPP Spot Rate (OECD Data), 1973-2010