Lancaster University
Management School

Economics Working Paper Series

2012/001

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Efthymios G. Pavlidis and Nicos G. Pavlidis

The Department of Economics
Lancaster University Management School
Lancaster LA1 4YX
UK

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Efthymios G Pavlidis[a] and Nicos G Pavlidis[b]

[a]Department of Economics, Lancaster University Management School, Lancaster LA1 4YX, UK

[b]Department of Management Science, Lancaster University Management School, Lancaster LA1 4YX, UK

Abstract

The difficulty of measuring trade costs is well documented. We propose a nonlinear state-space model that enables us to extract information about changes in trade costs directly from real exchange rates. The model is well grounded in theory and nests numerous widely used empirical real exchange rate models. By employing two centuries of data on the Dollar-Sterling rate, we provide evidence of substantial variation in trade costs over time. Our results indicate that the process of economic integration that started after World War II has stopped during the last decades. We also contrast our results with a measure from the gravity literature and explore implications for the Purchasing Power Parity puzzle.

Keywords: Purchasing Power Parity; Time-Varying Trade Costs; Smooth Transition Nonlinearity; Particle Filter; Commodity Market Integration.

JEL Classification: F3, C22, C51

1 Introduction

Trade costs play a central role in international economic models, in policy formation, and in the decision making process of individuals and firms. The incorporation of trade costs in international macroeconomic models for example helps to explain several well-known puzzles, such as the home bias in trade, the home bias in equity, and the apparent lack of efficient risk sharing among OECD countries (Obstfeld and Rogoff, 2000). With respect to policy formation, the experience from the two eras of globalization and the Great Depression suggests that tariffs, preferential trade arrangements, and other policy related factors may impact on economic growth and social welfare (see, e.g., O'Rourke, 2000; Meissner, 2012, and the references therein).[1] This historical experience has led to the foundation of international organisations, like the International Monetary Fund and the World Trade Organisation, whose operations aim to remove trade barriers and promote international trade. Finally, at a more micro level, several trade impediments are viewed by firms as major "obstacles for doing business" (see, e.g., the World Bank survey of 3,685 firms on 69 countries conducted by of Brunetti *et al.*, 1997, and the discussion in Anderson and Marcouiller, 2002).

Despite the widely recognized importance of trade costs, their measurement poses numerous challenges and there is no single universally accepted measure. The reason is that trade costs consist of numerous components, some of which are unobservable or hidden (Hummels, 1999; Anderson and van Wincoop, 2004). Three broad categories of trade-costs measures have been proposed in the literature: direct measures, measures based on trade flows, and measures based on prices (for a survey see Anderson and van Wincoop, 2004). This paper focuses on the latter category.

Price-based measures rely on the notion that international prices and trade costs are linked by arbitrage operations, so that as the degree of commodity market integration increases prices converge. On this basis, empirical studies have employed deviations from the Law of One Price (LOOP)

[1] Theoretical models also demonstrate how trade costs can affect social welfare (Krugman, 1989).

and Purchasing Power Parity (PPP) to infer the evolution of commodity market integration (see, e.g., Friedman and Schwartz, 1982; Findlay and O'Rourke, 2003; O'Rourke and Williamson, 1999). The analyses so far, however, are mostly narrative and a-theoretical, and a comprehensive assessment of the underlying relationship is missing (Anderson and van Wincoop, 2004). Our primary goal is to fill this gap by drawing on recent developments in the nonlinear PPP literature and Bayesian econometrics.

A number of international macroeconomic models illustrate how the presence of trade frictions induces nonlinearity into the PPP deviation process (Dumas, 1992; Sercu *et al.*, 1995; O'Connell and Wei, 2002). Intuitively, trade costs create a band of inaction around the equilibrium real exchange rate. Inside this band the shipping of goods across countries is not beneficial and the speed of mean reversion of the real exchange rate is increasing with its distance from the equilibrium level. The theoretical prediction of nonlinear dynamics provides (at least partially) an explanation for the well-documented high persistence and volatility of actual real exchange rate series during the recent float. Furthermore, it has motivated the application of a variety of nonlinear econometric models such as Threshold Autoregressive (TAR) and Smooth Transition Autoregressive (STAR) (Obstfeld and Taylor, 1997; Michael *et al.*, 1997; Taylor *et al.*, 2001; Kilian and Taylor, 2003). A key aspect of commodity markets highlighted by historical studies on market integration but typically not incorporated in univariate nonlinear PPP models is that trade costs vary over time. Time variation arises from numerous factors such as technological improvements, trade agreements and wars. The main implication for PPP models is that the width of the inaction band changes over time with the level of trade costs. Thus, the extension to time-varying nonlinear autoregressive models follows naturally.

In this paper, we formulate a time-varying Quadratic Logistic STAR model (TV-QLSTAR) in a state-space form. We treat trade costs as the unobserved state variable and employ particle filtering for estimation. This approach has several appealing features. First, nonlinear state-space models are more flexible than nonlinear autoregressive models that incorporate time trends to accommodate structural change, such as the Time-Varying STAR model of Lundbergh *et al.* (2003). Second, the proposed nonlinear state-space formulation provides a general framework for modeling deviations from arbitrage conditions in the presence of time-varying market frictions. Thus, it is widely applicable in economics and finance.[2] Third, the TV-QLSTAR is well grounded in economic theory since the econometric specification closely resembles the properties of the dynamic general equilibrium model of Dumas (1992). Fourth, the model provides rich information about trade costs since it allows one to extract the entire probability distribution of the trade-costs index rather than a single point estimate. From an international macroeconomic point of view, the TV-QLSTAR adds a new perspective to the PPP puzzle by allowing the degree of real exchange rate persistence to vary over time with the unobserved degree of trade restrictiveness. As we will show later, this property is important for explaining the documented high persistence of real exchange rates over the recent floating period. Finally, estimation of the TV-QLSTAR requires only price data. Since price data is more readily available over long time periods than trade volumes (Taylor, 2002), this is an advantage over gravity models.

We apply our method to the Dollar-Sterling real exchange rate for the period from 1791 to 2010. This period is particularly interesting because, on the one hand, dramatic changes in trade policies and technological improvements have occurred and, on the other, there is remarkably little evidence about the evolution of goods market integration over the late 20th century (Findlay and O'Rourke, 2003). Moreover, the question of whether the degree of commodity market integration is higher now than during the first era of globalization has attracted the attention of a number of authors (Frankel, 2000; Bordo *et al.*, 1999; Findlay and O'Rourke, 2003). Our findings show that the degree of commodity market integration (as measured by the price-based trade-costs index) changed substantially and non-monotonically over time. It remained low during most of the 19th century, an era of economic integration driven by technological improvements. It rose substantially in the

[2] For example, apart from PPP deviations, the TV-QLSTAR can be used to model deviations from covered interest parity (Peel and Taylor, 2002) and Dollar-Sterling gold points (Clark, 1984; Canjels *et al.*, 2004).

first half of the 20th century, reflecting the rise of protectionism during the two World Wars and the Great Depression, and gradually declined after World War II, without reaching however its pre-19th century levels. Most importantly, during the last decades the process of economic integration that started after World War II appears to have stopped.

Since actual trade costs are unobservable we contrast the evolution of the proposed price-based measure with that of a recently proposed measure from the gravity literature (Jacks *et al.*, 2011). We find that the two approaches yield similar predictions. Finally, we explore implications of our results for the PPP puzzle. By using generalized impulse response analysis we show that movements in the price-based trade costs index are associated with substantial changes in the persistence of the Dollar-Sterling real exchange rate over time. With respect to the comparison of the two eras of globalization, we show that the real exchange rate process is more persistent in the recent floating period than in the second half of the 19th century due to higher trade costs.

The remaining paper is structured as follows. The next section outlines the theoretical framework. Section 3 describes the empirical model and the particle filtering estimation procedure. The following section deals with the estimation results, the comparison with the gravity model, and the implications for the PPP puzzle. The final section concludes.

2 A Spatially Separated World

Dumas (1992) considers a world consisting of two spatially separated countries. The countries have identical preferences (given by a constant-relative-risk-aversion instantaneous utility function) and produce a homogeneous good, that can be consumed, invested in a stochastic constant-returns-to-scale production process or shipped abroad. A key feature of the model is that transportation of goods across geographical locations entails costs, so that only a fraction of the initial shipment reaches its destination. The rest melts during transit. In a narrow sense these iceberg costs include shipping costs. More broadly, they consist of all barriers to trade such as information, time and insurance costs, costs associated with different languages, tariff and nontariff policy barriers, but also the sunk costs of international arbitrage and the resulting tendency for traders to wait for substantial arbitrage opportunities (Taylor *et al.*, 2001; Anderson and van Wincoop, 2004).

The central planner's welfare problem is to maximize the present value of current and expected future rewards:

$$V(K^H, K^F) = \max_{c^H, c^F, X^H, X^F} E_t \int_t^\infty e^{-\rho(u-t)} \left[\frac{1}{\zeta} \left(c_u^H \right)^\zeta + \frac{1}{\zeta} \left(c_u^F \right)^\zeta \right] du, \tag{1}$$

subject to:

$$dK_t^H = (\alpha K_t^H - c_t^H)dt + \sigma K_t^H dz_t^H - dX_t^H + s dX_t^F, \tag{2}$$

$$dK_t^F = (\alpha K_t^F - c_t^F)dt + \sigma K_t^F dz_t^F + s dX_t^H - dX_t^F, \tag{3}$$

where H and F indicate home and foreign variables, respectively, ρ is the discount rate, $1 - \zeta$ is the degree of risk aversion, α is the expected rate of return and σ the standard deviation characterizing the production processes, z_t^H and z_t^F are two independent Wiener processes that represent production shocks which cause capital imbalances, c denotes consumption, and X^H and X^F denote the cumulative capital that has been shipped from H and F, respectively. The parameter s is a shipping-loss factor which determines the unit iceberg cost of transferring capital - defined as $\tau \equiv 1 - s$.

In the absence of impediments to trade, $\tau = 0$, the concavity of the utility function makes trade beneficial in all cases other than when the home and foreign capital stocks are the same. Thus, in line with the international risk sharing principle, the central planner's optimal policy is simply to eliminate capital imbalances (i.e. differences in instantaneous utilities) by capital transfers. This ensures that the real exchange rate, $Q \equiv \left(\frac{\partial V / \partial K^H}{\partial V / \partial K^F} \right)$, is continuously equal to the PPP rate. At the other extreme, when trade costs are infinite, trade is never beneficial and there is autarky. In this

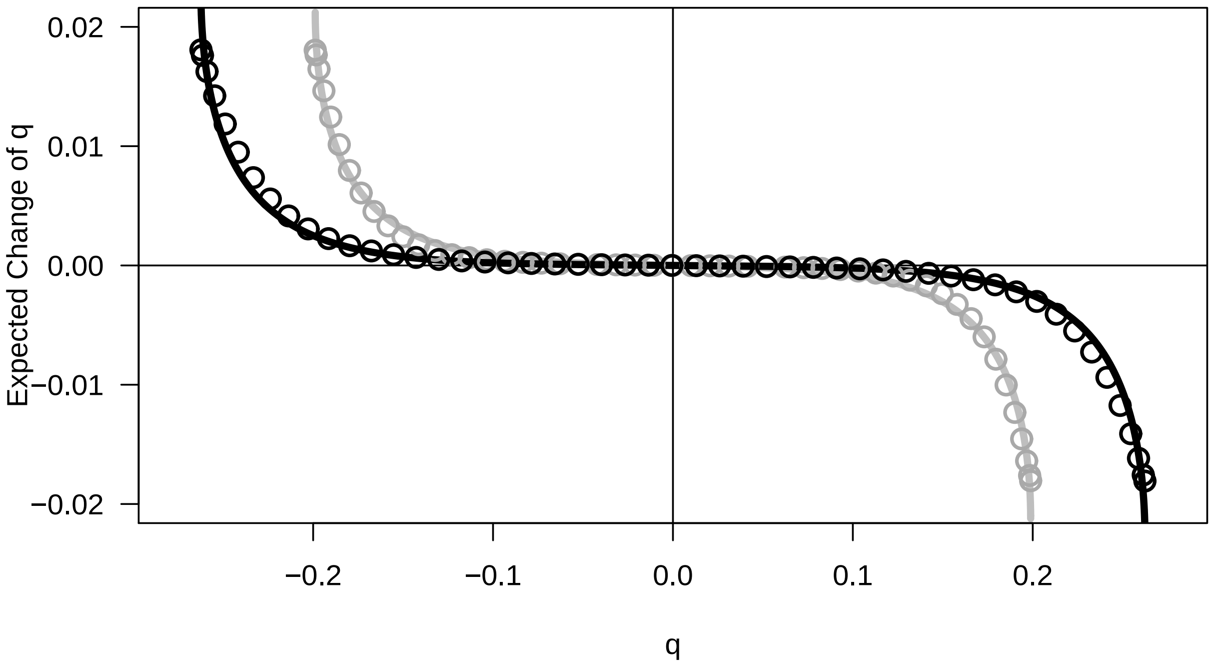

Figure 1: The expected change of the log real exchange rate against the deviation from the PPP rate in the model of Dumas (1992) for high (black solid line) and low (grey solid line) trade costs, and the QLSTAR approximation (circled lines).

setting, changes in the real exchange rate follow a martingale process. Finally, when trade costs are finite, a region exists within which no trade takes place. Differences in capital stocks can arise and persist due to a series of random production shocks but shipping eventually occurs at the edges of the capital imbalance fluctuation band. Similarly to economic fundamentals, the real exchange rate displays rich dynamics.

Figure 1 depicts the drift of the $\log$ real exchange rate against the deviation from the equilibrium rate suggested by PPP for two levels of trade costs, $\tau = 1 - 1/1.22$ (solid grey line) and $\tau = 1 - 1/1.3$ (solid black line). As in the analysis of Dumas (1992), the remaining parameter values are $\rho = 0.15$, $\zeta = 0.9$, $\sigma = 0.5$ and $a = 0.11$. By focusing on either line, we observe that the log real exchange rate moves inside a band, similar to a target zone model (see, e.g., Svensson, 1990). Near the equilibrium level there is high persistence (as measured by the drift of the process), whilst, at the edges of the band persistence is low. The transition between persistence regimes is smooth, the reason being that the real exchange rate reflects the probability of the economy hitting the boundaries and this probability decreases smoothly with the magnitude of the deviation from PPP. In contrast to the prediction of the PPP models of Roll (1979) and Adler and Lehmann (1983), the change in the real exchange rate process is not a martingale. This property, however, violates neither rational expectations nor market efficiency.

A comparison of the grey and black solid lines in Figure 1 illustrates the impact of a change in trade costs on the functional form of the real exchange rate adjustment process. Higher trade costs widen the band of inaction and induce higher persistence for a given PPP deviation with only one exception, the equilibrium rate. As an implication, the unconditional volatility of the real exchange rate also increases. In the next section, we operationalize the idea of time-variation in the nonlinear adjustment mechanism of the real exchange rate.

3 A Time-varying Nonlinear PPP Model for the Estimation of Trade Costs

A general QLSTAR representation for the log real exchange rate process in the presence of constant trade costs is given by:

$$q_t = \mu + G(q_{t-d}; \gamma, \tau_p, \mu) \sum_{i=1}^{p} \phi_i (q_{t-i} - \mu) + \epsilon_t, \tag{4}$$

where μ represents the long-run equilibrium; ϵ denotes the error term which is assumed to be i.i.d. $\mathcal{N}(0, \sigma_\epsilon^2)$; $\gamma \in (0, \infty)$ is the *smoothness* parameter; $\tau_p > 0$ is the *band* parameter; and $G(\cdot)$ is the quadratic logistic transition function given by:

$$G(q_{t-d};\gamma,\tau_p,\mu) = 1 - \left(1 + e^{-\frac{\gamma}{\tau_p}\left((q_{t-d}-\mu)^2-\tau_p\right)}\right)^{-1}. \tag{5}$$

The above model is particularly attractive due to the flexibility of the quadratic logistic transition function to take various shapes (van Dijk, 1999). Because of this property the QLSTAR model approximates or even nests several widely used empirical PPP models such as the random walk, the linear autoregressive, the three regime TAR, and the Exponential STAR. It also closely resembles the properties of the dynamic general equilibrium model of Dumas (1992) outlined in the previous section (see Pavlidis *et al.*, 2011).

Figure 1 plots the econometric adjustment mechanism (4) for $\gamma = 6.52$ and $\tau_p = \{0.06, 0.11\}$ together with its theoretical counterpart for the two levels of trade costs considered in the previous section.[3] [4] From the figure we can see that the QLSTAR provides a very close approximation to the theoretical adjustment mechanism for low trade costs (grey lines). We also observe that the change in the theoretical functional form of the real exchange rate induced by increasing the level of trade costs is closely tracked by the QLSTAR model by simply allowing the *band* coefficient to change. Two important implications follow from the relationship between the level of trade costs τ and the *band* coefficient τ_p. First, τ_p comprises a price-based trade-costs index grounded in theory. Second, the time-invariant QLSTAR model can be extended to capture potential changes in the level of trade costs in a straightforward manner by simply letting τ_p vary over time.

[3]For fitting the econometric model to the theoretical adjustment mechanism, we employ the methodology of Pavlidis *et al.* (2011). First, we solve for the theoretical expected change of the real exchange rate process by using a shooting method and the 4^{th} order Runga-Kutta technique. This gives us one locus of points in the $(E(\Delta q), q)$ space for low trade costs and one for high. Next, we fit a restricted version of the regression model (4) to the numerically-obtained theoretical points for low trade costs. The imposed restrictions are based on the theoretical framework and include setting $\mu = 0$, $p = 1$ and $\phi = 1$, which leaves us with two unknown coefficients the *smoothness* parameter γ and the *band* parameter τ_p. The estimated coefficients for low trade costs are 6.52 and 0.06, respectively. Next, we repeat the estimation step for high trade costs but this time we also fix γ to 6.52, i.e. we allow only the band parameter to change as we move from low to high trade costs. The τ_p estimate is 0.11.

[4]With respect to the PPP puzzle, an interesting conclusion that emerges from the figure is that neglecting movements in trade costs leads to a misspecification of the functional form of the adjustment process. As we will illustrate in the empirical results section, this misspecification can bias measures of persistence, such as half-lives.

3.1 Particle Filtering

We propose the following state-space model formulation for the evolution of the trade-costs index and the real exchange rate:

$$\tau_{p,t+1} = \tau_{p,t} + \eta_{t+1}, \tag{6}$$

$$q_{t+1} = \mu + G(q_{t-d}; \gamma, \tau_{p,t+1}, \mu) \sum_{i=1}^{p} \phi_i (q_{t+1-i} - \mu) + \epsilon_{t+1}. \tag{7}$$

In this formulation the trade-costs index, which constitutes the state variable in Eq. (6), follows a one-sided truncated normal distribution, $\tau_{p,t+1} \sim TN(\tau_{p,t}, \sigma_\eta^2, 0, \infty)$. This restriction stems from the fact that as a trade-costs index τ_p must always be positive. Information about τ_p is obtained indirectly through the observation of the log real exchange rate at each period. Recursive Bayesian filtering provides a very general framework to solve such recursive estimation problems.

In our brief exposition of recursive Bayesian filtering and the particle filter it will prove useful to denote the state transition and the measurement equations as:

$$\tau_{p,t+1} | \tau_{p,t} \sim p(\tau_{p,t+1} | \tau_{p,t}),$$

$$q_{t+1} | \tau_{p,t+1} \sim p(q_{t+1} | \tau_{p,t+1}).$$

The objective of filtering is to construct the posterior probability density function (pdf) of the state variable given all the available information up to the current time, $p(\tau_{p,t+1} | q_1, \ldots, q_{t+1}) = p(\tau_{p,t+1} | Q_{t+1})$, $t = 1, 2, \ldots, n$. Assuming that the posterior pdf is known at time t, then filtering can be viewed as a two stage procedure. In the first stage, Eq. (8), the posterior pdf from time t is propagated into the future through the transition density, giving rise to the *propagation density*. In the second step, Eq. (9), information from the measurement at time $t + 1$ is incorporated through

Bayes theorem, leading to the *filtering density*:

$$p(\tau_{p,t+1}|Q_t) = \int p(\tau_{p,t+1}|\tau_{p,t})p(\tau_{p,t}|Q_t)d\tau_{p,t}, \tag{8}$$

$$p(\tau_{p,t+1}|Q_{t+1}) = \frac{p(q_{t+1}|\tau_{p,t+1})p(\tau_{p,t+1}|Q_t)}{p(q_{t+1}|Q_t)}. \tag{9}$$

For the state-space model of Eq. (6) and (7) the equations of the recursive Bayesian filter can not be solved analytically. We therefore need to resort to Particle Filters (PFs) to track the trade-costs index over time.[5] Since their introduction PFs have become a very popular class of numerical methods for the solution of optimal estimation problems in nonlinear non-Gaussian state-space models (see Doucet and Johansen, 2011; Lopes and Tsay, 2011, for recent reviews). In this work we utilize the version of the particle filter proposed in (Gordon *et al.*, 1993), which is also known as the Bootstrap PF. This filter can be seen as a direct mechanisation of the recursive Bayesian filter using Sequential Monte Carlo.

The central idea behind the Bootstrap PF is to draw a set of i.i.d. particles $\left\{\tau^j_{p,t+1}\right\}_{j=1}^N$ to approximate $p(\tau_{p,t+1}|Q_{t+1})$ starting from a set of i.i.d. particles $\left\{\tau^j_{p,t}\right\}_{j=1}^N$ that approximates $p(\tau_{p,t}|Q_t)$. The Bootstrap PF performs a Sampling Importance Resampling procedure at each step. Following Lopes and Tsay (2011) the workings of the Bootstrap PF can be expressed as:

$$p(\tau_{p,t+1}, \tau_{p,t}|q_{t+1}, Q_t) \propto \underbrace{p(q_{t+1}|\tau_{p,t+1})}_{\text{2. Resample}}\underbrace{p(\tau_{p,t+1}|\tau_{p,t})p(\tau_{p,t}|Q_t)}_{\text{1. Propagate}}. \tag{10}$$

The Bootstrap PF first propagates each particle $\tau^j_{p,t}$ through the transition equation to obtain a sample from the prior at time $t+1$. The propagated samples are subsequently resampled with weights proportional to their likelihood given the measurement from time $t+1$.

[5] An alternative approach would be to linearize the problem by taking a first order Taylor series expansion about $\tau_{p,t} = E(\tau_{p,t}|Q_{t-1})$ where Q_{t-1} is the information set available at time $t-1$ and then use the standard Kalman filter for estimation. However, Taylor series expansions can generate large biases and the resulting filter is not optimal (Mariano and Tanizaki, 1995).

In the thus far exposition of filtering we assumed that all the quantities involved in the state transition and measurement equations are known, with the exception of the state variable that is not observed. In our case, the parameters $\mu, \gamma, \sigma_\epsilon^2$ of the QLSTAR model that comprises the measurement equation, as well as the variance of the noise term in the state transition equation σ_η^2, and the initial value of the state variable, $\tau_{p,0}$, are unknown. Parameter learning is an active field of research in the particle filter literature and several methods have been recently proposed for both online and offline estimation (Lopes and Tsay, 2011). In this work we obtained maximum likelihood estimates of the parameters by optimising directly the likelihood $p(Q_N|\theta)$, where $\theta = (\mu, \gamma, \sigma_\epsilon^2, \sigma_\eta^2, \tau_{p,0})$ and N is the length of the time series. To ensure that the estimated likelihood estimate for each θ considered was as accurate as possible we used a very large population of particles, equal to $3 \cdot 10^4$.

4 Empirical Results

We employ a dataset of annual observations on the Dollar-Sterling real exchange rate for the period from 1791 to 2010. The U.S. and U.K. price series and the nominal exchange rate data are from Lothian and Taylor (1996) for the period 1791 to 1993, and the International Financial Statistics thereafter.

The first two rows of Table 1 report parameter estimates and standard errors for a QLSTAR(2) model that assumes static trade-costs over time.[6] Overall, the model performs reasonably well. The smoothness and band coefficients are correctly signed and statistically significant at the five percent nominal significance level. Residual diagnostics illustrate that the error term suffers from neither conditional heteroskedasticity nor serial correlation up to lag order four.[7]

[6]Model selection is based on residual diagnostics and statistical significance of parameters. The autoregressive parameters are restricted to sum to unity, $\sum \phi_i = 1$. This restriction implies that the process exhibits (near) unit root behavior at the inner regime and allows fast convergence of the nonlinear least squares algorithm.

[7]The ARCH and LM serial correlation test-statistics are equal to 0.30 and 0.07, and the corresponding p-values are 0.87 and 0.99.

Table 1: The fitted QLSTAR and TV-QLSTAR models for the Dollar-Sterling real exchange rate.

	$\widehat{\mu}$	$\widehat{\phi}$	$\widehat{\gamma}$	$\widehat{\tau}_p$	$\widehat{\sigma}_\epsilon$	$\widehat{\sigma}_\eta$
QLSTAR	1.599	1.186	2.866	0.188	0.069	–
s.e.	0.018	0.076	0.595	0.045	–	–
TV-QLSTAR	1.630	1.220	2.837	–	0.067	0.038

Notes: The table reports parameter estimates and standard errors (s.e.) for the constant QLSTAR and time-varying QLSTAR models described in Section 3.

Parameter estimates for the TV-QLSTAR model are reported in the third row of Table 1. Comparing the static QLSTAR with the TV-QLSTAR, we do not observe large differences in the estimated parameters. The standard error of the time-varying regression, $\widehat{\sigma}_\epsilon$, is slightly smaller than that of the static QLSTAR. Nevertheless, there are important differences in the economic implications of the two models.

Figure 2 displays the evolution of the median of the price-based trade-costs index, $\tau_{p,t}$, together with the upper and lower quartiles. The figure illustrates that trade costs exhibited wide fluctuations over the past two centuries. During the first part of the sample, trade costs remained low and reached their minimum at the second half of the 19th century. This period coincides with significant technological advances in the transportation of goods (most notably the trans-Atlantic steam service, mechanical refrigeration, and railroad networks) and communications (e.g., the trans-Atlantic telegraph cable). The technological advances coupled with the Gold Standard and the free-trade policy that Britain adopted after the abolishment of the Corn Laws appear to have driven economic integration and to have initiated the first era of globalization (Findlay and O'Rourke, 2003).

The period of economic integration between the U.S. and the U.K. ended with the onset of the American Civil War and was followed by a prolonged period of disintegration. US tariffs were increased during the war in an attempt to raise revenues. After the war, the Republican-controlled Congress kept tariffs high as a response to declining import prices (Irwin, 1998). The protectionist policies adopted aimed to shield infant industries from European competition (O'Rourke, 2000).

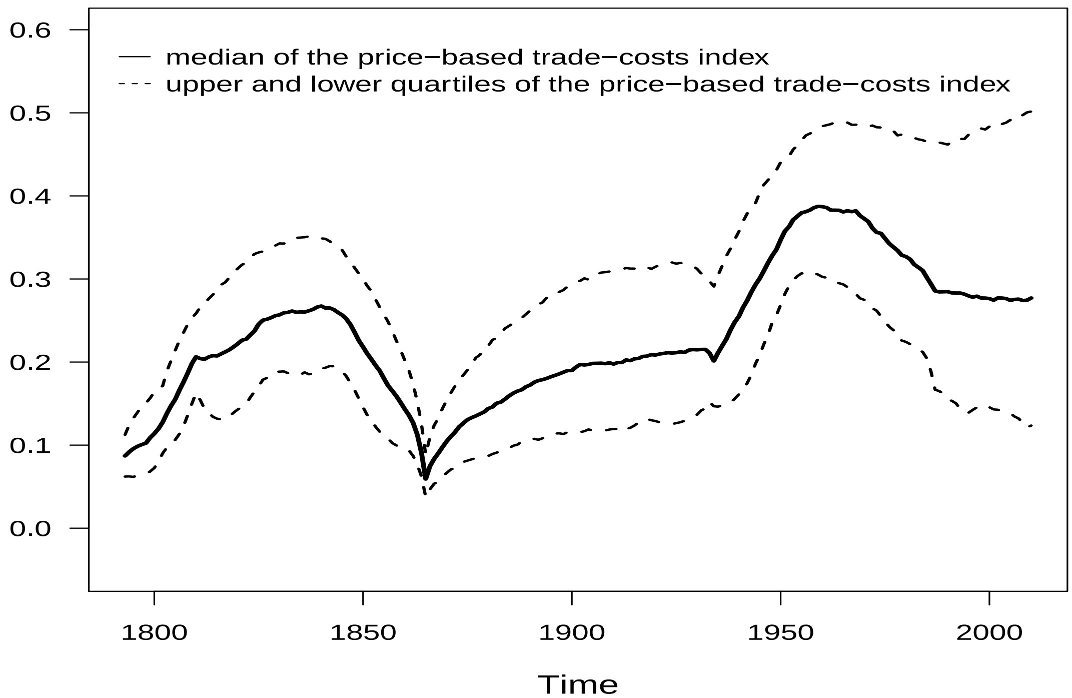

Figure 2: Time evolution of the median (solid line), the lower and the upper quartiles (dashed lines) of the price-based trade costs index.

On the counterpart, Britain's free-trade policy was interrupted by World War I. The onset of the war was followed by the imposition of tariffs and price controls, and the abandonment of the Gold Standard (Friedman, 1974). The forces of economic disintegration became even stronger during the interwar period - especially the Great Depression and World War II- with a proliferation of protectionist policies from both sides. The high degree of trade restrictiveness is identified in the literature as one of the main reasons for the global trade implosion of that time (Madsen, 2001).

Trade liberalization started after World War II with the General Agreement on Tariffs and Trade and the Bretton Woods system. Similarly to the first era of globalization, trade liberalization was accompanied by technological improvements such as the jet aircraft engine and containerization (Hummels, 2007). However, the estimated trade costs index suggests that the degree of commodity market integration after World War II did not reach the level attained during the first era of globalization. Even more interesting is the finding that the process of economic integration that characterized the second half of the 20th century appears to have slowed down during the last decades. In the next subsection we show that measures of trade costs based on bilateral trade flows lead to the same conclusion.

4.1 A Comparison with the Gravity Literature

Gravity models provide an alternative approach to infer the magnitude of trade costs. Inspired by Newton's law of gravitation, these models link trade flows to country size and distance. Anderson and van Wincoop (2003) derive the following simple gravity equation:

$$x_{i,j} = \frac{y_i y_j}{y_w} \left(\frac{t_{i,j}}{\Pi_i P_j} \right)^{1-\sigma}. \tag{11}$$

The above equation determines trade flows in an $N-$country world with differentiated goods and CES preferences. The variable $x_{i,j}$ denotes nominal exports from country i to j; y_i, y_j and y_w denote income levels of country i, country j and world income, respectively; $\sigma \geq 1$ is the elasticity of substitution; $t_{i,j} \geq 1$ is the cost of importing a good, the trade cost barrier (one plus the tariff equivalent); and Π_i and P_j are price indexes (or outward and inward multilateral resistance variables) which measure average trade restrictiveness. Because multilateral resistance variables are hard to proxy measuring trade costs from Eq. (11) is not straightforward. Jacks *et al.* (2011) circumvent this obstacle by making use of the fact that Eq. (11) applies also to intranational trade. This allows the authors to derive the following micro-founded trade costs measure:[8]

$$\tau_g \equiv \left(\frac{t_{i,j}t_{j,i}}{t_{i,i}t_{j,j}}\right)^{\frac{1}{2}} - 1 = \left(\frac{x_{i,i}x_{j,j}}{x_{i,j}x_{j,i}}\right)^{\frac{1}{2(\sigma-1)}} - 1. \tag{12}$$

τ_g measures bilateral trade costs relative to the domestic trade costs benchmark. Intuitively, a rise in international trade costs relative to domestic costs causes a drop in international trade with respect to intranational trade and, consequently, an increase in τ_g. An appealing feature of Eq. (12) is that estimation requires only data on exports and GDP. The latter proxies for intranational trade.

Figure 3 plots the gravity trade costs measure and the price-based measure from 1830 to 2010.[9] Both series have been normalized to permit comparisons. We observe that the two lines share a similar pattern. The main conclusion that follows is that measures based on the nonlinear PPP and the gravity literatures make similar predictions for the evolution of commodity market integration. These predictions are not, however, identical. First, the price-based measure suggests that the degree of commodity market integration increased by a larger amount than that suggested by the gravity measure around the middle of the 19th century. Second, according to the price-based

[8] The authors suggest multiplying Eq. (11) by exports from country j to i in order to obtain the following bidirectional gravity equation:

$$x_{i,j}x_{j,i} = \left(\frac{y_i y_j}{y_w}\right)^2 \left(\frac{t_{i,j}t_{j,i}}{\Pi_i P_j \Pi_j P_i}\right)^{1-\sigma}.$$

In turn, they argue that intranational trade, like international trade, is a function of trade barriers $x_{i,i} = (y_i y_i / y_w)(t_{i,i}/(\Pi_i P_i))^{1-\sigma}$. By dividing the bidirectional equation by the product of intranational trade they manage to control for multilateral resistance, $x_{i,j}x_{j,i} = x_{i,i}x_{j,j}((t_{i,j}t_{j,i})/(t_{i,i}t_{j,j}))^{1-\sigma}$, and rearranging yields the gravity trade-costs measure.

[9] International trade data are taken from Mitchell (2008b,a) and GDP series for the United Kingdom and the United States are taken from Officer (2008) and Johnston and Williamson (2008), respectively. We have used the Hodrick-Prescott filter to extract the long-term trend of the gravity measure, τ_g.

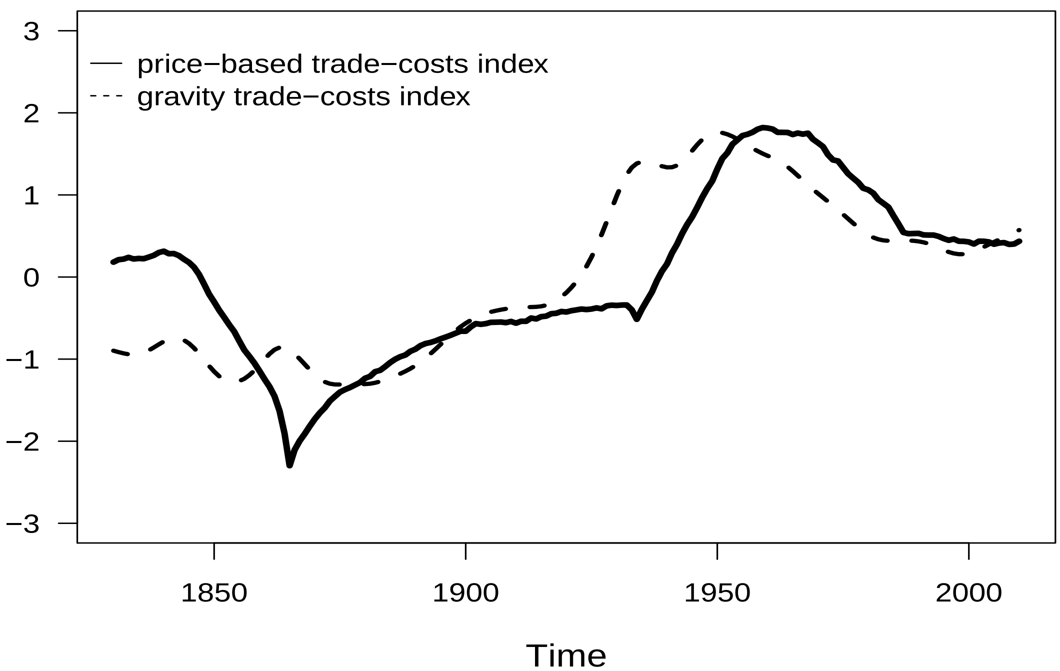

Figure 3: Time evolution of the price-based (solid line) and the gravity (dashed line) trade-costs indices.

measure the large increase in trade barriers in the first half of the 20th century and the subsequent decrease in the second half of the 20th century occurred later than what is suggested by the gravity measure. In the next section, we explore the impact of movements in the price-based trade-costs measure on the persistence of PPP deviations.

4.2 The PPP Puzzle in Historical Perspective

It is a stylized fact that deviations from PPP are highly persistent and volatile. The estimates reported in the literature suggest that, on the one hand, half-lives of shocks can reach several years, whilst on the other, the volatility of real exchange rates is of the same magnitude as that of nominal rates. The fact that one cannot reconcile the very slow adjustment with the extreme short run volatility of deviations from an arbitrage condition gave rise to the PPP puzzle (Rogoff, 1996).

Several possible explanations for the PPP puzzle have been put forth in the literature (for a survey see Taylor and Taylor, 2004). Perhaps the most important is provided by theoretical analyses that demonstrate how trade frictions induce nonlinear dynamics in the real exchange rate process, such as the one examined in Section 2. Rogoff (1996, p. 665) infers from the behavior of real exchange rates during the recent floating period: "*International goods markets, though becoming more integrated all the time, remain quite segmented with large trading frictions across a broad range of goods...This is not an entirely comfortable conclusion, but for now there is no really satisfactory explanation to the purchasing power parity puzzle.*" The existence of trade costs has motivated the development and application of nonlinear econometric models. Most of these models are based on the assumption that trade costs are time-invariant. The results presented in this paper and in previous studies on market integration indicate that this assumption might not be valid.

We use generalized impulse response analysis in order to examine the impact of movements in the price-based trade-costs index on the persistence of the Dollar-Sterling real exchange rate.[10]

[10] The Generalized Impulse Response Function (GIRF) is defined as the average difference between two realizations

Figure 4 displays half-lives for the time-varying QLSTAR model against time for two shock sizes: one equal to the maximum realized PPP deviation (solid line) and one equal to half of the maximum PPP deviation (dashed line). It is evident that the effect of changes in trade costs on the speed of mean reversion of the real exchange rate is substantial. Conditioning on the large shock, the massive increase in trade costs from the second half of the 19th century to the 1950s is associated with an increase in the estimated half-lives from a single year (the shortest possible) to six years. After the 1950s, the persistence of the real exchange rate declined without reaching however its pre-World War I levels. The time pattern of the estimated half-lives supports the argument of McCloskey and Zecher (1984) that PPP performed well under the Anglo-American Gold Standard. Furthermore, it is in line with the documented high persistence of real exchange rates during the recent floating period (Taylor and Taylor, 2004).

Regarding the effect of the shock size, Figure 4 shows that large shocks are absorbed faster than small shocks. This is intuitive since large shocks push the real exchange rate process closer to the boundaries where mean reversion is faster (see also Section 2). The estimated difference in half-lives between large and small shocks is three to four years. Since half-lives depend on the magnitude of the shock only when the process is nonlinear, this three to four years difference provides empirical support for the presence of substantial nonlinearities in the real exchange rate mechanism.[11] Overall, our findings suggest that the real exchange rate process is both nonlinear and time-varying.

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of the stochastic process, q, which start with identical histories up to time $t-1$, but only the first realization is hit by a shock at time t. Due to the fact that analytic expressions for the estimation of GIRFs are generally not available when the model is nonlinear we use monte carlo integration methods (Koop *et al.*, 1996). In particular, we generate 800 samples by randomly drawing future shocks from a normal distribution with mean zero and variance equal to the estimated residual variance, and then we average the results for each time horizon. The half-live is defined as the minimum horizon beyond which the difference between the impulse responses at all longer horizons and the ultimate response is less than or equal to half of the difference between the initial impact and the ultimate response (van Dijk *et al.*, 2007).

[11] Half-lives for nonlinear models may also depend on the sign of the shock. This is not the case for the QLSTAR model since adjustment is symmetric.

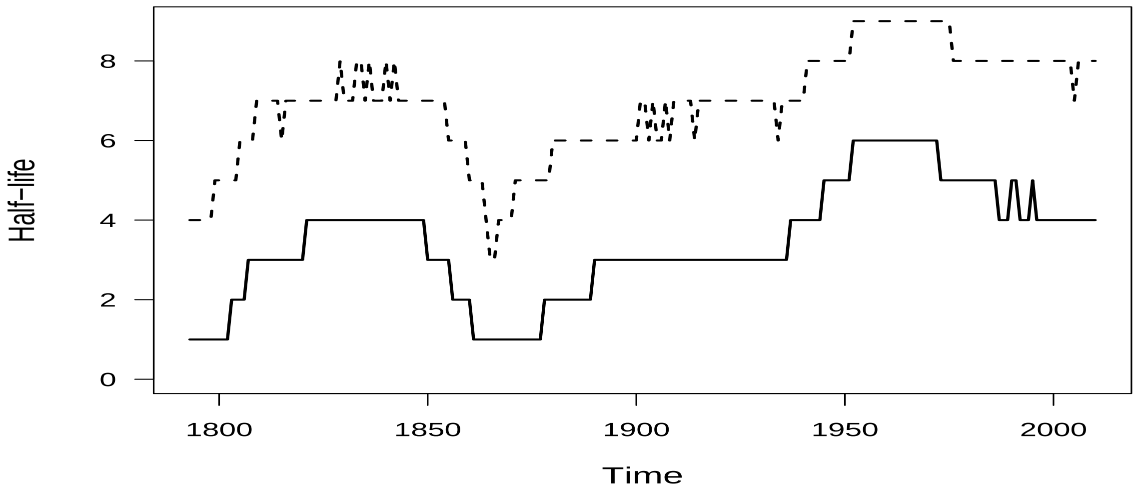

Figure 4: Time evolution of half-lives for shocks equal to the maximum realized PPP deviations (solid line) and half the maximum (dashed line).

5 Conclusion

It is well recognized that trade costs play an important role in economic modeling and policy formation. Trade costs capture all impediments to international trade and as such it is difficult to quantify through a single measure. We propose a time-varying nonlinear autoregressive model for the real exchange rate, where trade costs are treated as a state variable, and adopt a particle filtering approach for estimation. The model builds on the empirical nonlinear purchasing power parity literature and closely resembles the properties of the real exchange rate suggested by the theoretical analysis of Dumas (1992).

By fitting the model to a long span of data on the Dollar-Sterling rate, we provide evidence of substantial changes in the level of trade costs over the last two centuries. The evolution of the price-based trade costs index is in accordance with the findings of historical studies. It is also quite similar to the microfounded measure of Jacks *et al.* (2011) that relies on trade flows rather than prices to measure trade costs. Both measures agree on two points. First, the process of commodity market integration that started after World War II has stopped during the last decades. Second, the degree of commodity market integration is lower now than during the first era of globalization. This result supports the explanation of Rogoff (1996) that the documented high persistence of the real exchange rate during the recent floating period can be attributed to the high level of trade costs.

The nonlinear state-space formulation proposed in this paper is a general framework for modeling deviations from arbitrage conditions in the presence of time-varying market frictions. Potential future research includes modeling deviations from arbitrage conditions other than purchasing power parity, such as the covered interest parity and the law of one price.

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