The Efficiency of the Global Market for Capital Goods

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Abstract

Despite integration of financial and goods markets, borders still impose considerable friction to flows of goods. In this paper we compare the efficiency of the global market of commodities with the market for capital goods. We construct a novel measure of the real exchange rate based on capital goods and estimate the costs of moving goods across borders directly from time series properties of the real exchange rate process. This process is derived from a continuous time stochastic general equilibrium model, which has not previously been estimated. We estimate this model by indirect inference, employing a two-regime autoregressive model (ESTAR) as auxiliary model.

For the period 1974 to 2007 estimated relocation cost among 18 developed countries range from 14% to 63% for capital goods, and from 6% to 30% for commodities. Border frictions in markets for capital goods are thus substantially higher than in markets for commodities. For commodities as well as for capital goods, relocation costs are found to be smallest between country pairs where one country is economically much larger than the other, and between countries which are culturally or geographically related. Relocation costs for capital goods vary widely across country pairs; especially within Continental Europe they are disproportionately large.

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1 Introduction

During the last three decades not only consumption goods, but also capital goods have become increasingly mobile. Despite globalization of financial and goods markets, however, borders still impose considerable friction to flows of goods. These frictions may vary considerably between goods: For commodities, on the one side, these frictions may have shrunk to the pure transportation cost. But for more sophisticated products, on the other side, which need to be adapted to the local environment, relocation can be complex. Differences in standards, culture, skill and local technology levels may lead to adaption costs for these goods, which are higher than the cost of transporting commodities.

Studies of market frictions embodied in borders have previously focused on commodities, that is, on goods which are similarly useful in all countries, and do not require localization. We will refer to these goods as *unbundled goods*, or *commodities*. Previous estimates of market frictions were based on trade flows (McCallum 1995, Anderson and van Wincoop 2003) and on the real exchange rate of commodity-type consumer goods (Engel and Rogers 1996). No estimates exist, however, of the relocation costs of more complex goods, such as *capital goods*. Capital goods comprise, for example, machinery, technology, and human capital embedded in the productive sector, which is why we will refer to them also as *bundled goods*. Estimates for capital goods are crucial for measuring the efficiency of allocations in this market. As a matter of fact, the allocation of capital goods among countries has been of great interest in economics at all times (Lucas 1990, Hsieh and Klenow 2007), as it is a key determinant of relative output and ultimately of relative living standards. Large relocation costs lead to severe and persistent deviations from the optimal allocation of goods across countries. These distortions could dwarf the appraised efficiency gains by the global integration of financial markets (Gourinchas and Jeanne 2006).

Because a prerequisite for an efficient allocation of capital goods are negligible relocation costs across country borders, we want to know how big these relocation costs for capital goods are, and how these costs relate to the cost of transferring commodities. The key questions to be answered are therefore: How wide is the border for commodities and for capital goods? Does border width differ, and, if so, why? Answering these questions has direct implications for relative market efficiency and thereby for determining which market would most benefit from additional effort in reducing these frictions.

A natural approach to these questions would start with data on goods' allocations among countries, which is, especially for capital goods, available only as a rough estimate. We therefore choose an indirect approach. Already Heckscher (1916) has pointed out that under non-zero relocation costs large deviations from purchasing power parity (PPP) can be sustained. Sercu, Uppal and van Hulle (1995) and especially Dumas (1992) have formally derived the link between relocation cost, allocations of goods and the real change rate.[1] Their fundamental insight allows us to analyze the real exchange rate in lieu of the allocation of goods across countries. In these models, relocation costs affect the real exchange rate in a unique way, which we exploit for estimating these costs.

An important innovation of our approach is the estimation of relocation cost directly from movements of the real exchange rate over time. Unlike previous studies, we do not rely on differences of price index levels between countries alone. Models of international finance predict not only bounds on sustainable price differences between two countries. As a matter of fact, the essence of any continuous time model is that its solution describes the entire real exchange rate process, in particular the evolution of drift and diffusion over time. We utilize predictions from a Dumas (1992)-type model on conditional drift and diffusion to estimate the "width of the border" (Engel and Rogers 1996). Importantly, the model predicts a nonlinear process, which can parsimoniously be represented by an exponential smooth autoregressive (ESTAR) model. Accordingly, we use an ESTAR model as auxiliary model in an indirect inference framework.

Our estimation framework exploits the information contained in the nonlinearity of the time series of real exchange rates and allows us to attribute this nonlinearity to relocation costs. Whereas nonlinearity in real exchange rates is a well-documented phenomenon (Prakash and Taylor 1997, Obstfeld and Taylor 1997, Michael, Nobay and Peel 1997, Taylor, Peel and Sarno 2001, Imbs, Mumtaz, Ravn and Rey 2003),[2] it has not previously been used to quantify the cost of moving goods across borders.

Several authors have estimated the nonlinear ESTAR specification for the real exchange rate based on the consumer price index (CPI).[3] Michael et al. (1997), for example, use a

[1] Costs of international trade have also been included in international business cycle models, e.g. Backus, Kehoe and Kydland (1992), Obstfeld and Rogoff (2000), Ravn and Mazzenga (2004).

[2] The importance of a nonlinear specification is highlighted by the weak support for mean-reversion achievable with linear models (Adler and Lehman 1983, Frankel and Rose 1996, Lothian and Taylor 1996, Rogoff, Froot and Kim 2001). Froot and Rogoff (1995) and Sarno (2005) provide useful surveys. These studies imply extremely slow speeds of mean reversion (Rogoff 1996, Murray and Papell 2005). In the same vein, conventional methods such as unit root tests typically do not reject a random walk hypothesis. Nonlinear models provide a natural explanation for both observations. The real exchange rate mean-reverts whenever it has wandered far away from its equilibrium value, but follows a random walk close to the equilibrium level.

[3] See Taylor (2005) for a survey. At the sectoral level Imbs et al. (2003) find nonlinearity for two thirds of the sectors in their sample. Other authors have estimated the threshold autoregressive (Tong 1990, Balke and Fomby 1997) model, which specifies a hard cut-off between regimes, e.g. Prakash and Taylor (1997) and Obstfeld and Taylor (1997).

sample of monthly data of four countries in the 1920s and annual data for UK-France and UK-US over 200 years. Taylor et al. (2001) work with monthly data for five countries over the period 1973-1996. All studies report strong support for a nonlinear specification. Using ESTAR, Kilian and Taylor (2003) find predictability of real exchange rates over two years or more. At shorter horizons the random walk dominates.

Studies focusing on mean reversion of relative nominal international stock prices, such as Richards (1995) and Balvers, Wu and Gilliland (2000), find evidence of transitory country-specific effects in long-run relative stock returns. The mean reversion of a real capital market based measure, such as the real exchange rate for capital goods, has not previously been investigated.

Since conventional data of real exchange rates is based on the price index for unbundled goods, e.g. on the CPI or wholesale price index (WPI), its behavior over time will reflect the frictions in the market for unbundled goods. It cannot be expected to provide information on the market for capital goods, because these goods are simply not contained. For this reason, we construct a novel measure of the real exchange rate based on capital goods. The new measure complements the existing measures by focusing on a class of goods neglected so far, and thus allows us to compare its properties with conventional real exchange rate series.

This paper is organized as follows. Section 2 introduces the methodology we use, including our measure, data and model. Section 3 describes the estimation and inference procedure. Section 4 presents the results, and section 5 concludes.

2 Methodology

2.1 Model

We model an economy with complete financial markets, i.e. all necessary securities are available and international financial flows are unconstrained.[4] The counterpart of financial markets in the real economy, the market for goods, is subject to frictions. Relocating goods from one country to another entails a cost, $1 - r \in (0, 1)$, i.e. of every unit relocated only r percent arrive. This relocation cost reflects first and foremost the shipping cost for moving an unbundled good itself. For capital goods this cost contains additionally the

[4] Completeness seems an accurate description of the condition of financial markets among developed countries over the past 30 years, considering the immeasurable variety of financial instruments. Between developed countries, movements of financial capital were largely free from legal restrictions. See e.g. Allen and Gale (1994).

cost of relocating organizational structures and knowledge necessary for operating the good. Whereas the shipping cost component for capital goods might be negligible, the overall cost can therefore be much higher than for commodities.

Our model economy consists of two countries, which are separated by a border. There is only one good in our economy, but because any transfer of goods across the border entails an "iceberg" loss of $1 - r$, the good's location matters.[5] Accordingly, we mark parameters and quantities of the foreign country with an asterisk (*). The stock of goods, K, can be either consumed (c) or invested in a constant returns to scale production with productivity α. The stock of goods is subject to a zero-mean depreciation shock, $d\tilde{z}$. Further, the shocks in both countries have a joint covariance matrix Ω, and thus

$$\begin{pmatrix} d\tilde{z} \\ d\tilde{z}^* \end{pmatrix} = \Omega \begin{pmatrix} dz \\ dz^* \end{pmatrix} = \begin{pmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{12} & \sigma_{22} \end{pmatrix} \begin{pmatrix} dz \\ dz^* \end{pmatrix}, \tag{1}$$

where dz and dz^* are increments of a standard Brownian motion process.

Under this setup – perfect financial markets and imperfect markets for goods – the economy is always in equilibrium.[6] The marginal rates of substitution, however, differ between countries at almost every instance, because of the cost of crossing the border. Therefore, the real exchange rate, p, between countries tracks the relative scarcity of goods – a scarcity due to the frictions in the goods market. Since the relocation cost is the only friction hindering the movement of goods, this relocation cost bounds the possible price differences between countries from above. No real exchange rate outside of the interval $[r; 1/r]$ can persist, because this would trigger immediate, risk-free and profitable transfers of goods, dX, from a low price to a high price country, until the real exchange rate has returned back into the interval.

Owing to the assumption of complete financial markets, the decentralized two-country problem is identical to the planner's problem:[7]

$$V(K, K^*) = \max_{\substack{c(t), c^*(t), \\ \Xi(r)}} E_t \int_0^\infty e^{-\rho(u-t)} \left(\frac{q}{\gamma} c(u)^\gamma + \frac{1-q}{\gamma} (c^*(u))^\gamma \right) du \tag{2}$$

[5] On that account, there are two goods, indexed by their location, and a relocation technology, r.

[6] This setup differs from a class of finance models, where a "mispricing" of stocks or other assets constitutes an arbitrage opportunity that triggers e.g. foreign direct investment (Baker, Foley and Wurgler 2004) or investment (Polk and Sapienza 2004), or where imperfect capital markets cause foreign direct investment to be linked with e.g. currency movements (Froot and Stein 1991).

[7] Basak and Croitoru (2007) show that a decentralized economy with country specific bonds and a claim on the dividend flow of one country can equivalently be solved by (2).

s.t.

$$\begin{aligned} dK(t) &= (\alpha K(t) - c(t))\,dt + K(t)d\tilde{z}(t) - dX(t) + rdX^*(t) \\ dK^*(t) &= (\alpha^* K^*(t) - c^*(t))\,dt + K^*(t)d\tilde{z}^*(t) + rdX(t) - dX^*(t) \end{aligned} \tag{3}$$

where $K(0)$ and $K^*(0)$ are given, $c(t), c^*(t), K(t), K^*(t), X(t), X^*(t) \geq 0 \quad \forall t$, and where $\rho > 0$ denotes the discount rate, $1 - \gamma > 0$ the risk aversion and q the welfare weight of the home country. The relocation of goods is captured by $X(t)$, which is an adapted, non-negative, right-continuous, nondecreasing stochastic process. Ξ denotes the open region in the (K, K^*) space in which no goods are transferred, i.e. where $dX = 0$ and $dX^* = 0$. Due to the homogeneity of the value function, Ξ is fully characterized by the minimal and maximal imbalance levels, $\underline{\omega}$ and $\overline{\omega}$.

The symmetric version of the model has been developed by Dumas (1992).[8] We consider here, in addition, country heterogeneity in the ability to produce capital goods (Hsieh and Klenow 2007), which can result in persistent differences of prices between countries. This complication of the analytic and subsequent numerical solution becomes important when estimating this model, because only an asymmetric model can explain, for example, an unconditional non-zero mean of the drift of the real exchange rate.

We define the *imbalance* of goods as $\omega = K/K^*$. Substituting $V(K, K^*) = K^{*\gamma} I(\omega)$,[9] and using the homogeneity property of the value function, we obtain a second order differential equation, which governs the imbalance process in periods of no relocations.

$$\begin{aligned} 0 &= \left(\frac{1}{\gamma q} - q^{\frac{1}{1-\gamma}}\right) I'(\omega)^{\frac{\gamma}{\gamma-1}} + \left(\frac{1}{\gamma(1-q)} - (1-q)^{\frac{1}{1-\gamma}}\right) \left(\gamma I(\omega) - \omega I'(\omega)\right)^{\frac{\gamma}{\gamma-1}} \\ &+ \left(\alpha^*\gamma - \rho + \frac{1}{2}\left(\sigma_{12}^2 + \sigma_{22}^2\right)\gamma(\gamma-1)\right) I(\omega) \\ &+ \left[\alpha - \alpha^* + (\gamma-1)(-\sigma_{22}^2 - \sigma_{12}^2 + \sigma_{12}(\sigma_{11} + \sigma_{22}))\right] \omega I'(\omega) \\ &+ \omega^2 I''(\omega) \left(\frac{1}{2}\left(\sigma_{11}^2 + \sigma_{12}^2\right) + \frac{1}{2}\left(\sigma_{22}^2 + \sigma_{12}^2\right) - \sigma_{12}(\sigma_{11} + \sigma_{22})\right) \end{aligned} \tag{4}$$

By optimal choice of the boundary of Ξ the unknown function $I(\omega)$ must satisfy value

[8] This model is also related to the models of Sercu et al. (1995) and O'Connel and Wei (2002), which predict a no-arbitrage band as well. Versions of this model have been used by e.g. Uppal (1993) to analyze the effect of home bias in consumption on portfolio choice, and by Dumas and Uppal (2001) to assess the benefit of international financial integration.

[9] The technical appendix, which is available upon request, provides additional calculation details. (Appendix **??**)

matching and smooth pasting conditions at both boundaries for all t. The value matching condition requires equalization of marginal values of the good at the moment of relocation, e.g. for the upper boundary[10]

$$V_K(K, K^*) = rV_{K^*}(K, K^*). \tag{5}$$

The smooth pasting conditions require

$$V_{KK}(K, K^*) = rV_{KK^*}(K, K^*), \tag{6}$$

and

$$V_{K^*K}(K, K^*) = rV_{K^*K^*}(K, K^*). \tag{7}$$

Substituting for the value function we can express these conditions in terms of the unknown functional $I(\omega)$.

$$\frac{I'(\overline{\omega})}{\gamma I(\overline{\omega})} = \frac{r}{1 + r\overline{\omega}} \tag{8}$$

$$\frac{I''(\overline{\omega})}{\gamma I(\overline{\omega})} = \frac{r^2(\gamma - 1)}{(1 + r\overline{\omega})^2} \tag{9}$$

The differential equation (4) with boundary conditions (8) and (9) and the analogous conditions for the lower boundary must be solved numerically for the function $I(\omega)$. We determine the optimal boundaries by guessing values for $\underline{\omega}$ and $\overline{\omega}$ and iterating both forward toward some intermediate imbalance level $\omega_0 \in (\underline{\omega}, \overline{\omega})$ using the embedded fifth order Runge-Kutta method of Cash and Karp (1990).[11] If $\overline{I'(\omega_0)} = \underline{I'(\omega_0)}$ and $\overline{I''(\omega_0)} = \underline{I''(\omega_0)}$ then a solution has been found. Otherwise we retry with a new guess for the pair of boundaries.

[Table 1 about here.]

[Table 2 about here.]

Table 1 reports the maximum sustainable imbalance as a function of risk and risk aversion for modest relocation cost ($r = 0.82$) in a symmetric world.[12] The imbalances are the larger, the lower the risk aversion and the higher the risk. Table 2 shows that at a higher relocation cost ($r = 0.66$) the sustainable imbalances increase for any level of risk aversion and risk.

[10]The conditions for the lower boundary are analogous.
[11]This procedure is described in detail in Press, Teukolsky, Vetterling and Flannery (2001), p.710.
[12]A part of this table has been shown in Dumas (1992).

[Table 3 about here.]

When the productivity of the home country exceeds the productivity of the foreign country ($\alpha > \alpha^*$), then, as shown in table 3, the sustainable abundance of goods increases in the highly productive country, and decreases in the less productive country, but this difference shrinks quickly as risk aversion increases. Given a degree of risk aversion, the maximum sustainable imbalance approaches an asymptote as risk grows to infinity. For risk aversion larger than unity there exists a maximum risk level, beyond which the differential equation has no solution.[13]

We are now able to define the *real exchange rate*, p, as the ratio of the marginal values of the good in two countries, i.e.

$$p(\omega) = \frac{V_1(K, K^*)}{V_2(K, K^*)} = \frac{I'(\omega)}{\gamma I(\omega) - \omega I'(\omega)}. \tag{10}$$

Note that the real exchange rate depends only on the capital goods imbalance, ω, but not on the stock levels, K and K^*, of the good. This underlines the strong impact of relative productivity on the real exchange rate.

Using Ito's lemma, drift and diffusion of the real exchange rate process

$$dln(p) = \mu_p(p)dt + \sigma_p(p)dz \tag{11}$$

can be written as a function of ω, $I(\omega)$, $I'(\omega)$, $I''(\omega)$.[14]

The drift of $ln(p)$ is at the upper boundary

$$\mu_p(\omega = \overline{\omega}) = \alpha^* - \alpha + \frac{\overline{\omega} - 1/r}{\overline{\omega} + 1/r}(1-\gamma)\sigma^2, \tag{12}$$

and at the lower boundary

$$\mu_p(\omega = \underline{\omega}) = \alpha^* - \alpha + \frac{\underline{\omega} - r}{\underline{\omega} + r}(1-\gamma)\sigma^2. \tag{13}$$

For realistic parameter values the mean reversion at the boundary gains in strength with shock diffusion, σ^2, and with risk aversion, $1-\gamma$.[15]

[13]The technical appendix, which is available upon request, derives solutions for special cases and for specific values of ω. (Appendix **??**)

[14]These expressions are derived in the technical appendix, which is available upon request. (Appendix **??**)

[15]The necessary condition for this to hold is $\underline{\omega} < r$ and $\overline{\omega} > 1/r$. Tables 1 and 2 show that this is always satisfied except for very small σ in combination with $\gamma < 0$.

[Figure 1 about here.]

Figure 1 graphs the model-implied drift and diffusion, both for the symmetric case ($\alpha = \alpha^*$, solid line) and for the asymmetric case ($\alpha > \alpha^*$, dashed line). The upper panel shows the drift of the real change rate. A deviation of the real exchange rate level from parity entails a drift of opposite sign. At the same time, as the lower panel shows, the diffusion decreases as the real exchange rate deviations from parity become large. The real exchange rate process is therefore mean reverting at the boundaries of Ξ, but is indistinguishable from a random walk close to parity. The dashed line shows how differences in growth rates shift the real exchange rate, to which the process reverts, away from PPP ($ln(p) = 0$). If two countries have a big productivity gap, then the drift can in fact have the same sign at all real exchange rate levels.[16] In this case the real exchange rate process is therefore divergent for half of its support, although it is still bounded by Ξ.[17]

2.2 Measure

The model described in the previous section helps us estimating the relocation cost directly from real exchange rate data. Typically the real exchange rate is calculated for commodities, and based on the CPI, the WPI, or deflators of the gross domestic product (GDP). Each of these excludes a large share of the capital goods required for production, in particular immaterial goods. To compare the border effect of commodities with that of capital goods, we need one real exchange rate series for each.

For commodities we use the real exchange rate based on the WPI, which captures the bulkiness and business-to-business nature of these goods.[18]

For capital goods no appropriate real exchange rate is readily available. As mentioned in the introduction, capital goods are factors in operation in the productive sector of the

[16] An example for this is shown in figure 17.

[17] Although this model does not contain any non-tradeables, it has empirical implications in line with the "Harrod-Balassa-Samuelson" effect (Harrod 1933, Balassa 1964, Samuelson 1964), which says that countries with high productivity (in tradeables) have higher price levels. In the model presented here the capital scarce country is in expectation the low productivity country. The real exchange rate of this country is high, but falls due to the negative drift. This means that although the model predicts the opposite *levels* of the real exchange rates, it predicts the same *direction* of change. A special case obtains when the risk is very low and relocation costs are small. Then the last terms in (12) and (13) are dominated by the productivity differential. For very large productivity differentials the drift of the exchange rate does not change its sign, i.e. a already high real exchange rate increases further. Effectively, the productivity advantage dominates the diversification motive.

[18] An alternative to the WPI, although available only at quarterly frequency, would be the producer price index, which was used by e.g. Kim and Ogaki (2004).

economy. They are typically owned by a firm, need to be combined with other capital goods in order to be fully useful,[19] and are often intangible, e.g. in the form of patents and knowhow.

None of the aforementioned real exchange rates focuses on capital goods, in fact for the most part they do not contain them at all. To understand more clearly what data we need, let us rewrite (10) by reducing the fraction to higher terms using the world market price of uninvested capital good, V_G.

$$p(\omega) = \frac{V_K(K, K^*)K/(V_G K)}{V_{K^*}(K, K^*)K^*/(V_G K^*)} \tag{14}$$

Notice that the market value of all capital goods in a given country can be written as

$$M = V_K\left(K(t), K^*(t)\right) K(t)e(t), \tag{15}$$

where $e(t)$ is the nominal exchange rate to a numeraire currency. Likewise, book values of all capital goods in a given country are

$$B = V_G K(t)e(t)\varphi, \tag{16}$$

where φ denotes a time-invariant, country-specific accounting constant. The real exchange rate (14) can therefore be written in terms of (inflation-adjusted) market-to-book ratios, M/B, i.e.

$$p(\omega) = \frac{M/B}{M^*/B^*}\frac{\varphi}{\varphi^*}. \tag{17}$$

Stock indices measure the total market value of capital goods of firms included in this stock index. The corresponding quantity of capital goods is captured by the aggregate book values,

[19] A major share of capital goods, except machinery, can be considered complementary factors. The work of Caselli and Feyrer (2007) highlights the importance of these complementary factors for understanding global capital goods allocations. They find that under a narrow definition of capital stocks (i.e. machinery only) the marginal product of capital across countries does not differ by much, and thus frictions for these goods between countries are small. It is the other, complementary capital goods needed in the production process, such as human capital and technology, that explain the difference in marginal product of capital. They point out that the scarcity of complementary capital goods, which are included in the capital goods definition employed in this paper, and the higher cost of capital goods explains the low capital flows into these countries. Our model predicts a similar link between high cost of capital and low new investment. Without relocations, the less productive country is short of capital goods. Because relocation costs hinder a complete equalization of this imbalance, the price of capital goods in the less productive country is higher. The model predictions match therefore the empirical observation of Caselli and Feyrer (2007), but the causality is reversed.

after adjusting it for the effect of inflation. Normalizing the stock indices by adjusted book values removes the effect of nominal exchange rates and of quantity changes by e.g. retained earnings or a international relocation of capital goods, and thus provides us with a measure of the relative value of one unit of capital good. For countries with identical accounting standards the real exchange rate of capital goods is thus simply the ratio of market-to-book values. When countries differ in accounting standards or leverage levels, $p(\omega)$ can be corrected for the constant factor $\frac{\varphi}{\varphi^*}$ by setting midrange of $log(p(\omega))$ to zero.

Our use of market-to-book ratios differs from their interpretation in standard q-theory (Hayashi 1982). Our aim of dividing market by book values is normalizing market values to one unit of capital goods, and since the value of capital goods changes over time, the market-to-book ratio must change as well. In contrast, Tobin's q in our model is always unity, because our model does not impose any adjustment cost of investment within a given country.[20] In our setup, the market-to-book ratio of a single country's stock index has no economic meaning in isolation, but is informative relative to other countries' market-to-book ratios. The ratio of two countries' market-to-book ratios measures the relative price of one unit of capital goods between the two countries.[21] Despite the different interpretation, high relative market-to-book ratios between two countries influence future relative returns – similar to the stylized fact that market-to-book ratios are inversely related to future equity returns (Fama and French 1992, Fama and French 1998, Pontiff and Schall 1998).

Our concept of the real exchange rate based on capital goods has multiple advantages. Firstly, it allows us to study properties of the market for capital goods in isolation from markets for other goods, which has not been done previously due to lack of data. In combination with our estimation approach this concept of the real exchange rate makes it possible to estimate relocation costs of capital goods from macro data. This is important, because information on the costs of relocating capital goods across borders is – at most – known on a per-project basis, but not publicly available.[22]

[20] Market-to-book values measure the ratio of the market value of equity relative to the book value of equity, i.e. the denominator includes the book value of all capital goods (including goodwill) minus the book value of debt. The model used does not distinguish between equity and debt. As long as within any given country the debt level is a fixed proportion of equity, dividing by book values provides the desired quantity correction.

[21] Because our model features only one type of capital good per country, constant returns to scale and perfect competition, the (average) valuation of capital goods in country A relative to their (average) valuation in country B is the same as the relative marginal value of capital goods between the two countries, and coincides with the relative market-to-book ratio.

[22] Available data, such as data on FDI, which might be used to identify frictions between countries, measures only financial flows, but not the underlying flow of capital goods.

Secondly, because one component of market-to-book ratios is determined in financial markets, it responds quickly to new information. In contrast, the revaluation of capital goods is restricted by accounting regulations (Nexia International 1993). The rare value adjustments of book values paired with frequent quantity adjustments, which makes book values inappropriate as a measure of value, is a virtue for our purposes. It makes, properly adjusted, book values a measure of the quantity of capital goods operating in an economy. Our approach mitigates problems with CPI and WPI data, which is subject to aggregation bias (Imbs, Mumtaz, Ravn and Rey (2005)) and non-synchronous sampling (Taylor (2001), p.489f). In particular, the valuation component of our real exchange rate, the market values, are synchronously sampled worldwide in centralized markets in a standardized and automated manner. It is collected in real time, and not subject to revisions. Further, aggregation to a country stock index is transparent and largely internationally comparable.

2.3 Data

We collected data from various editions of Capital International Perspective (1975-2007). This dataset from Morgan Stanley Capital International contains monthly nominal exchange rates, stock price indices and consistently calculated market-to-book ratios for these indices of 18 developed countries for the period December 1974 to June 2007.

[Figure 2 about here.]

The market-to-book ratios vary substantially over time. The solid line in figure 2 shows that the equal-weighted average market-to-book ratio trended upward over the last 30 years, with large transitory upward bursts. The variation across countries does not show any trend during the same period. In periods of a high market-to-book ratio average, however, the variation increases temporarily. This indicates that not all countries participate in these transitory upward bursts. Because variation after a few years returns back to the long-term level, this foreshadows mean reversion of relative market-to-book values between countries, and thus of the real exchange rate for capital goods.

We correct book values for the effect of inflation, using wholesale and consumer price index data provided by the International Monetary Fund's (IMF) International Financial Statistics database.[23] Figure 3 plots the effect of the book value correction for Germany.

[23] Inflation adjustment is based on the firm investment cycle. We assume a degressive depreciation schedule at a depreciation rate δ of 10%, i.e. $B_t = \sum_{i=0}^{\infty} \delta^i I_{t-i}$, which lets us calculate the approximate path of investment over time, $I_t = B_t - \delta B_{t-1}$. Adjusted bookvalues are therefore $\tilde{B}_t = \sum_{i=0}^{\infty} \delta^i I_{t-i} \Pi_{t-i}^t$, where Π_{t-i}^t denotes the WPI price deflator between period t and $t-i$.

In the high inflation periods of the 1970s this correction adjusts the original bookvalues (dashed line) upwards, as shown by the solid line, to match the overall inflation reflected in the market values.

[Figure 3 about here.]

Figure 4 shows the real exchange rate of capital goods between Germany and USA for the period 1974:12-2007:06 using this correction.

[Figure 4 about here.]

For wholesale price indices we use the the monthly wholesale price index from the IMF International Financial Statistics database for the same countries and time period.

[Figure 5 about here.]

[Figure 6 about here.]

[Figure 7 about here.]

[Figure 8 about here.]

Figures 5, 6, 7 and 8 compare our two measures of the real exchange rate. The real exchange rate based on capital goods, represented by the solid line moves less steadily than the real exchange rate for commodities, represented by the dashed line. Quite striking is the difference in evolution of the real exchange rate of capital goods during and after the new economy boom. Canadian capital goods (figure 6) reached their 30-year low in value relative to the USA shortly before the peak of the new economy boom, reflecting the delayed growth of this sector in Canada. In contrast, German capital goods (figure 5) reached their all time in the after-new-economy recession, which suggests that the recent recession had freed up more capital goods in Germany than in the USA.

Our model predicts a nonlinear relationship between returns and current levels of the real exchange rate. This kind of relationship is known to exist for commodities, as e.g. found by studies of Michael et al. (1997). For capital goods we find a similar relationship. We test the real exchange rate series for each of the 153 possible country pairs for ESTAR-type nonlinearity, using a Granger and Teräsvirta (1993)-type test. This test is based on a second order Taylor approximation of the ESTAR functional form around $\theta = 0$.[24]

[24] The test as well as detailed results are part of the technical appendix, which is available upon request. (Appendix **??**).

As expected, real exchange rates based on capital goods of most country pairs follow a nonlinear process as well. 52% of country pairs reject linearity at the 5% level, and 76% at the 10% level in favor of ESTAR-type nonlinearity. As illustration, figures 9 and 10 plot two-year changes in the real exchange rate of capital goods against the initial levels. Both country pairs feature random walk behavior close to the parity level and strong mean reversion away from parity. Visual inspection thus already points at nonlinearity with two regimes.[25]

[Figure 9 about here.]

[Figure 10 about here.]

3 Estimation and Inference

Our model has no closed form solution and but time-varying drift and diffusion which are unobservables due to the continuous-time setup. The estimation requires therefore a simulation-based approach.

3.1 Indirect Inference

This estimation problem ideally suits the indirect inference procedure, introduced by Smith (1993), Gouriéroux, Monfort and Renault (1993) and Gallant and Tauchen (1996). The idea behind indirect inference is using an auxiliary model that is close to the model of interest, but easier to estimate. One can then generate independent simulated data sets from the structural model for various parameter sets, estimate the auxiliary model with these simulated data, and repeat this procedure until parameters are found for which the estimates of the auxiliary model based on the simulated data are close by some metric to the estimates based on the actual data.

Whereas all simulation-based methods share the advantage of removing discretization bias, the specific advantage of indirect inference over the method of simulated moments (McFadden 1989, Pakes and Pollard 1989) is its ability to deal with continuous time and the latent process ω. Calculating $p(\omega_0)$ from ω_0 by (10) is a simple task, because the functional's value at ω_0, $I(\omega_0)$, is a by-product of calculating ω_0 via (4). The opposite

[25] Further, variance appears higher in the center than in the outer regime, in line with the predictions of our model. This may, however, be an effect of the relatively small number of observations in the outer regime.

direction, calculating ω_0 from $p(\omega_0)$ is not feasible, however, because the differential equation for p is not available in closed form. Hence, the conditional distribution of p_t given p_{t-1} cannot be simulated. In contrast, indirect inference does not require the calculation of the unobservable ω from the observed p. It allows us to solve and simulate the model for ω, and calculate then the implied real exchange rate corresponding to each ω level.[26]

3.2 Auxiliary Model

The most crucial decision in indirect inference is choosing an appropriate auxiliary model. In the problem at hand, a natural auxiliary model is the exponential smooth transition autoregressive model (ESTAR) of Haggan and Ozaki (1981) and Teräsvirta (1994). Whereas the process for p implied by our structural model is complicated and not available in closed form, its key feature, the smooth transition from a divergent to a mean reverting regime, can parsimoniously be modeled by the ESTAR specification. The ESTAR model has the following standard form:

$$\begin{aligned} p_t - p_{t-1} &= (1-\Phi(\theta; p_{t-d}-\mu))\left(\beta_0 + (\beta_1 - 1)p_{t-1} + \sum_{j=1}^{m}\beta_j p_{t-j}\right) + \\ &+ (\Phi(\theta; p_{t-d}-\mu))\left(\beta_0^* + (\beta_1^* - 1)p_{t-1} + \sum_{j=1}^{m}\beta_j^* p_{t-j}\right) + \epsilon_t \\ \epsilon_t &\sim N(0, \sigma_t^2) \end{aligned} \tag{18}$$

The transition function $\Phi(\theta; p_{t-d}-\mu)$, parametrized by the transition lag d and the transition parameter $\theta \geq 0$, governs the smooth transition between the inner autoregressive process with parameters β and the outer autoregressive process with parameters β^*:

$$\Phi(\theta; p_{t-d}-\mu) = 1 - exp\left(-\theta\left(p_{t-d}-\mu\right)^2\right) \tag{19}$$

Figure 13 plots a typical ESTAR transition function.[27] Unfortunately, the standard ESTAR model does not address conditional variance dynamics which our structural model (2) pre-

[26] The method of simulated moments would have to rely on unconditional moments, – in our highly nonlinear situation in particular on the kurtosis $E(p_t^4)$. Conditional heteroskedasticity may be captured by cross moments such as $E(p_t^2 p_{t-k}^2)$, and nonlinearity by moments such as $E((p_t - p_{t-1})^3 p_{t-1})$ or $E(p_t - p_{t-1}|p_{t-1} - E(p_t) > k)$. However, the use of conditional moments is likely to severely lower precision, as emphasized by Gouriéroux and Monfort (1996), p.137ff.

[27] The particular transition function shown is the estimate for the real exchange rate based on capital goods for the country pair Germany–USA and the time period 1974:12 – 2007:06.

dicts. Instead, the conditional variance, σ_t, is assumed to be the same for any p. Here, we generalize the standard ESTAR to allow for a time-varying conditional variance. Our specification uses a second transition function $\tilde{\Phi}\left(\tilde{\theta}; p_{t-d}-\mu\right)$, which smoothly moves between an inner regime variance σ_1^2 and an outer regime variance σ_2^2.[28]

$$\sigma_t^2 = \left(1-\tilde{\Phi}(\tilde{\theta}; p_{t-d}-\mu)\right)\sigma_1^2 + \left(\tilde{\Phi}(\tilde{\theta}; p_{t-d}-\mu)\right)\sigma_2^2 \tag{20}$$

$$\tilde{\Phi}\left(\tilde{\theta}; p_{t-d}-\mu\right) = 1-exp\left(-\tilde{\theta}\left(p_{t-d}-\mu\right)^2\right) \tag{21}$$

We follow Teräsvirta (1994) in specifying the transition lag, d, and number of autoregressive terms, m, based on the nonlinearity test of Granger and Teräsvirta (1993), where we restrict $d \leq 12$ and $m \leq 3$. Estimation of the ESTAR model is straightforward. Numerical difficulties arise only for country pairs, whose real exchange rate varies relatively little. For these countries the likelihood function has two local maxima, one "reasonable" maximum and one maximum combining very weak nonlinearity with an oscillating, nonstationary, outer regime.[29] We present results of the ESTAR model given by (18)–(21) for the country pair Germany-USA. The conditional mean dynamics for Germany-USA are highly sensitive to deviations from parity. As figure 11 shows, at relatively small deviations the process fully transits to the mean reverting outer regime. Only close the parity the inner, non-stationary regime dominates. The conditional variance is less sensitive, as illustrated by figure 12.

[Figure 11 about here.]

[Figure 12 about here.]

[Figure 13 about here.]

[Figure 14 about here.]

[Figure 15 about here.]

[28]Studies that allow for time-varying conditional variance in an ESTAR setup are scarce. A notable exception are Lundbergh and Teräsvirta (2006), who augment an ESTAR-type model with a GARCH variance process. For the nominal exchange rate of the Swedish krona and the Norwegian krone against a currency basket in the 1980s they find only a very weak decline of the conditional variance at the boundaries of the target zone set by the central bank.

[29]For about 1/4 of country pairs ESTAR has two pronounced local maxima. In about one half of these cases, the "reasonable" local maximum is the global maximum. The technical appendix discusses ESTAR estimation issues in more detail (Appendix **??**) and provides additional graphs and ESTAR estimation results for Italy-USA and Japan-USA (Appendix **??**).

From Michael et al. (1997) we already know that real exchange rates based on CPI can be modeled by an ESTAR process. The same applies to real exchange rates based on capital goods. For most country pairs this real exchange rate follows a nonstationary inner regime (figure 14) and a stationary outer regime (figure 15). The last row of table 4 shows that after accounting for the maximum weight put on the outer regime, all but one country pair follow a stationary outer regime. However, the individual coefficients of the mean equation are often insignificant. Conversely, the coefficient estimates of the variance equation are typically significant, but often with a higher variance in outer regime.

[Table 4 about here.]

3.3 Discretization, Simulation and Indirect Inference

Although the ESTAR estimates reveal nonlinearity in the data, they unfortunately do not provide a natural interpretation of the autoregressive coefficients.[30] Furthermore, we lack a natural benchmark for θ. If we wanted to ask whether θ is "big" or "small" we need to estimate the structural model. In our indirect inference framework ESTAR assumes then the role of the auxiliary model.

Inspection of the estimation equations (4) with (8) and (9) reveals that in a country-by-country estimation not all parameters can be identified. Importantly, however, because the countries have different productivities, the real exchange rate process need not be symmetric. Rather, it may be close to one boundary most of the time, and hardly ever reach the other. For this reason, we keep the productivity differential as a parameter to be estimated. Instead we assume equal variance $\sigma_{11} = \sigma_{22}$, and calibrate the covariance as $\sigma_{12} = 0.2$ and the discount rate as $\rho = 0.05$ based on business cycle evidence.[31]

The estimation requires the efficient simulation of many discrete trajectories of p for a given parameter set. We first simulate the ω process, which can be done with high precision because the diffusion of this process is constant. Wagner and Platen (1978) and Platen (1981) introduced an Itô-Taylor scheme which strongly converges at rate 1.5. This convergence excels the rate of 1.0 achieved by the well-known Milstein (1974) scheme.[32] Using the fact that the noise in our model is additive and the diffusion is constant, this scheme can be

[30]Except stationarity and "half-time of mean reversion"

[31]Cooley and Prescott (1995)

[32]See also Kloeden and Platen (1999) p.351.

written as

$$\begin{aligned}\omega_{t+1} &= \omega_t + \mu_\omega(\omega_t)\Delta + \sigma_\omega \Delta z_t + \mu'_\omega(\omega_t)\sigma_\omega \Delta y_t \\ &+ \frac{1}{2}\left(\mu_\omega(\omega_t)\mu'_\omega(\omega_t) + \frac{1}{2}\sigma^2_\omega \mu''_\omega(\omega_t)\right)\Delta^2,\end{aligned} \tag{22}$$

where $\Delta z_t = \sqrt{\Delta} u_1$, $\Delta y_t = \frac{1}{2}\Delta^{3/2}\left(u_1 + \frac{1}{\sqrt{3}}u_2\right)$, and $u_1 \sim N(0,1)$ and $u_2 \sim N(0,1)$ are independent.[33]

Next, we calculate the process of the real exchange rate from the process of imbalances, using the interim results $(I(\omega), I'(\omega))$ obtained in the calculation of the imbalance process. If numerical issues prohibit a successful Itô-Taylor step, we replace the Itô-Taylor step with a Milstein (1974) step.

We can now proceed with inference in the following way:

1. Estimate the ESTAR specification based on actual data by quasi maximum likelihood.[34] Denote the set of parameter estimates by $A_0 = \left\{\theta, \tilde{\theta}, \beta_i, \beta_i^*, \mu, \sigma_1, \sigma_2\right\}$.
2. Pick starting values for the parameters of the structural model, $B = \{\gamma, r, \alpha, \alpha^*, \sigma, q\}$.
3. Solve the differential equation for optimal boundaries, $\overline{\omega}$ and $\underline{\omega}$, using the Cash-Karp Runge-Kutta algorithm of order 5.
4. Simulate S=30 paths of the ω_t process by the Itô-Taylor scheme (Platen 1981) for $T = 391$ periods based on the structural model.
5. Calculate the price process $p(\omega_t)$ from the ω_t process.
6. Estimate the ESTAR specification for each of these S paths. Denote the set of parameter estimates by $A_s = \left\{\theta, \tilde{\theta}, \beta_i, \beta_i^*, \mu, \sigma_1, \sigma_2\right\}$, $s = 1, .., S$.
7. The indirect inference estimate of $\hat{B}$ is the set B that minimizes the distance between the data-based and the simulation-based estimate, measured by the score criterion

$$\hat{B} = \underset{B}{\operatorname{argmin}} \left[\sum_{s=1}^{S}\sum_{t=1}^{T} \frac{\partial \ln f^{ESTAR}}{\partial A}\left(p_t^s(B)|p_{t-1}^s, A_0\right)\right]'$$

[33] Another class of simulation schemes with a convergence rate of 1.0, the so-called Runge-Kutta methods (Kloeden and Platen 1999), do not require the calculation of explicit derivatives of drift and diffusion. In our case, however, all components of these derivatives must already be evaluated for the calculation of the drift and diffusion itself. Thus, nothing is saved by replacing differentials with differences.

[34] The more autoregressive terms the ESTAR model contains, the closer the indirect inference estimator becomes to the efficient method of moments estimator of Gallant and Tauchen (1996).

$$\times \quad \Omega \times \left[\sum_{s=1}^{S} \sum_{t=1}^{T} \frac{\partial \ln f^{ESTAR}}{\partial A} \left(p_t^s(B) | p_{t-1}^s, A_0 \right) \right], \tag{23}$$

where Ω is a nonnegative, symmetric weighting matrix.

4 Estimation Results

We apply our estimation procedure to both the real exchange rate of commodities as well as to the real exchange rate of capital goods. For France, Germany, Japan, United Kingdom and the USA table 5 shows the estimation results for commodities, and table 6 the corresponding results for capital goods.

The estimated transfer cost for commodities between these countries ranges from 13% for France–United Kingdom up to 33% for Japan–United Kingdom. With one exception, the preferences are estimated to be slightly more risk averse than logarithmic preferences.

The relocation cost, r, which is our key variable of interest, has the smallest standard error. This is not surprising, because the main aim of our estimation strategy was to capture this nonlinearity. For all country pairs the transfer discount is significantly different from zero and unity. That is, for the real exchange rate of commodities we reject both of the extremes random walk ($r = 0$) and constant ($r = 1$).

The relocation cost has a close relationship with economic proximity, similar to the "width of the border" in the trade literature. The lowest relocation cost exist between France, Germany and the United Kingdom. The highest relocation cost are country pairs involving Japan on one side, in particular Japan - USA, Japan - United Kingdom, France - Japan. Only between Germany and Japan a transfer seems to be less costly. An outlier is the country pair France - USA, where transfer costs are of similar magnitude as in the Japan country pairs.

The estimated productivity differentials provide a transitive ranking if Japan is excluded. UK as most productive, followed by the US, Germany and France. The shock variance is similar between country pairs, only for Germany–France it is particularly low. However, the productivities of and shocks to capital stocks, α and σ, vary too much to be economically meaningful.[35]

[Table 5 about here.]

[35]Note that α is the (mean) growth rate of capital goods *before* relocation. That is, any difference between the capital stock data (which is typically not available, and can only indirectly be inferred from investment and depreciation data) and our estimates for α are due to the relocation of capital goods between countries.

The picture changes dramatically when we shift the focus from commodities to capital goods. The second column of table 6 reports for all countries much larger relocation costs of capital goods than transfer costs of commodities, and a higher variation across countries. As with commodities, Japan country pairs have also the highest relocation cost for capital goods. Up to 58 % of the relocated quantity is lost between e.g. Japan–UK and Japan-USA. And as with commodities, again a relocation of capital goods between Germany and Japan is relatively less costly. Relocation costs are lowest between France, UK and USA with a relocation loss of around 30%. Relocating capital goods to and from Germany seems to be easier to Japan and the USA, than to the neighboring European countries. As for commodities, we reject a random walk ($r = 0$) for the real exchange rate of capital goods as well.

Risk aversion, $1 - \gamma$, is again generally slightly higher than in logarithmic preferences. The estimated productivities do not allow a transitive ordering of countries. The shock variance is somewhat higher for capital goods than for commodities. The pair UK–USA is subject to a particularly volatile stock of capital goods.

[Table 6 about here.]

Our parameter estimates allow us now to graphically compare the drift and diffusion processes. As an example, we discuss here the real exchange rate of capital goods for Germany–USA. The dashed line in the upper panel of figure 16 shows that the drift of the real exchange rate at parity is positive, which is an effect of the lower productivity of Germany relative to the USA and the, as a result, relative scarcity of capital goods in Germany. Only a large reduction in capital goods in Germany triggers a relocation of capital goods from the USA to Germany, because Germany itself produces capital goods a lower rate.

Figure 16 also emphasizes the large difference in border width between commodities and capital goods. The real exchange rate process for commodities, shown by the solid line, follows a much narrower band with lower diffusion than the process for capital goods. The nonlinearity, i.e. the maximum drift, however, is similar for both types of goods.

[Figure 16 about here.]

Figures 17 and 18 compare the real exchange rate process for capital goods of Germany–USA, shown as dashed line, with other countries.

[Figure 17 about here.]

As indicated earlier, the process for Japan–USA in figure 17 is hardly mean reverting at all for high real exchange rate levels, due to the high relocation cost and large productivity differential. It is nevertheless stationary, because the possible real exchange rate levels are always bounded by the possibility of relocation.

[Figure 18 about here.]

In contrast, figure 18 displays a country pair with very strong mean reversion and a narrow real exchange rate band. The country pair shown is United Kingdom – USA, which is among the country pairs with the lowest relocation costs for capital goods.

Table 7 compares the transfer cost of commodities with the relocation cost of capital goods directly. Relocation cost for capital goods among these five countries are found to be between 6% and 200% higher than transfer cost of commodities. For example Germany's borders, although among the least hindering for commodities, are as costly for capital goods to cross as borders between other countries. In contrast, moving any good across the border between the UK and the USA is relatively cheap.

[Table 7 about here.]

Looking at a larger set of countries pairs we find a positive correlation between relocation costs for capital goods and for commodities (figure 19).

[Figure 19 about here.]

[Table 8 about here.]

The left three columns of table 8 rank all countries in our sample by their cost of transferring commodities to and from the USA. By far narrowest border is the one between the USA and Canada. Less than 7% of the quantity of commodities crossing this border is lost in the form of iceberg costs. On the other extreme, a transfer of commodities from France to the USA incurs a cost of more than 30%. Small European countries have the smallest transfer costs of commodities to and from the USA.

The transfer costs of commodities for many country pairs are so small that they most likely consist only of transportation cost. Rogoff (1996), for example, compares free-on-board (fob) with customs-insurance-freight (cif) prices and reports transportation and insurance costs for commodities of about 10% in 1994. Between country pairs with higher transfer cost, however, additional friction, beyond pure geographic distance, seems to play a role.

The right three columns of table 8 rank the same countries again, but now by their cost of relocating capital goods to and from the USA. This reshuffles the ordering quite strongly. Asian economies form the group of countries with the highest relocation costs, each of them incurring a loss of more than 50%. Some countries with relatively high transfer costs of commodities, such as Italy and UK, have very low relocation costs of capital goods. Conversely, countries with low transfer costs of commodities, such as Canada and Austria, have high relocation costs of capital goods. Particularly open European countries, such as Netherlands, Switzerland and UK have low relocation costs of less than 25%. Nevertheless, this is still more than the transfer cost of commodities. Perhaps surprisingly, the relocation of capital goods between Italy and the USA seems to be easier than the relocation of commodities – only 14% of capital goods are lost in transit.

Until now we have derived a new measure for the width of the border, and found the width to be much larger for capital goods than for consumption goods. But what are the underlying causes that widen a border? To answer this question, we regress the natural logarithm of our border cost measures on factors commonly used in international trade. The independent variables are distance in 10000 kilometers, the 2003 GDP of the larger country in trillion USD at PPP, the sum of the 2003 GDP of both countries in trillion USD at PPP, a dummy for common language, a dummy for countries located in Continental Europe, and the number of cross-border mergers in 2003.

[Table 9 about here.]

Regression specification (1) in table 9 reveals that relative economic size strongly affects border width for both commodities and capital goods. Mergers, which may reflect information flows between a country pairs, are marginally significant for capital goods, but this may in fact be the result of endogeneity. Once we use instruments for the number of mergers its coefficient becomes insignificant.

Dropping all insignificant variables in the commodity regression, we arrive at specification (2). All coefficients are highly significant. Every additional 1000 kilometers of geographic distance increases the transfer cost of commodities by approximately 0.9%. But as McCallum (1995) and Engel and Rogers (1996) have pointed out, there is more to a border than just geographic distance. Whereas the effect of GDP of the large country cancels out, the GDP of the smaller country does matter. That is, the more two countries differ in economic size, the narrower is the border between them. For every trillion USD of small country GDP the transfer costs increase by approximately 5.7%. It might be that economies of smaller size adapt regulations and standards of the economically larger countries. This reduces the need for localization and thus may make the relocation of capital goods to and from economically large countries less costly.

The results for commodities are robust to adding a dummy for Continental Europe. For capital goods, however, the dummy for Continental Europe is marginally significant. As reported in specification (3) for $log(r_{CAP})$, a relocation of capital goods to and from Continental Europe incurs approximately 27.5% extra cost. Relocation cost for capital goods also increase with distance, more strongly than relocation goods for consumption goods. Every 1000 kilometers of geographic distance increase relocation costs by approximately 2.5%.

Even though we have already established mean reversion as a property of the real exchange rate, we have no notion yet of how long full mean reversion to the parity level will take. To do so we calculate the time that it takes the real exchange rate process on average to hit a boundary when started at parity, and the time it takes to revert to parity if started at the boundary. Despite mean reversion, these so-called hittimes are quite long, or, in the words of Rogoff (1996) "glacial". Table 10 shows the hittime for the example Germany–USA. The real exchange rate of commodities takes about 5 years from the boundary to the center and vice versa. For capital goods this time interval is more than twice that long.

[Table 10 about here.]

The hittime distribution itself is very skewed (figures 20 and 21), which makes outliers likely.

[Figure 20 about here.]

[Figure 21 about here.]

In summary, relocation costs of capital goods are larger than transfer costs of commodities. Border width for capital goods varies substantially across countries, much more than for commodities. The widest borders are between Western and Asian countries. As expected, geographic distance increases the width of the border, but relative economic size seems to matter as well. That is, a large country economically dominating a smaller country seems to facilitate the relocation of capital goods. Within Continental Europe, the relocation costs for capital goods are high compared to the rest of the world, even though transfer cost of commodities are not significantly different. The time from a maximum imbalance to balanced position is about 5 years for commodities for a typical country pair, and more than 10 years for capital goods. These long time spans obtain despite the real exchange rate process clearly does not follow a random walk. Overall, the market for capital goods is (still) less efficient than market for commodities and still far from perfect integration.

5 Summary

In this paper we have shown a novel approach to estimating the width of the border directly from real exchange rate series. We have found the border width to be considerably larger for capital goods than for commodities. This indicates that capital goods and commodities are at different stages of market integration. Large differences in economic size between two countries narrow the border, which could be the result of common standards that evolved due to the strong influence of the larger economy on the smaller one. Given the high relocation cost estimates of capital goods, the markets for capital goods would benefit most from additional policy attention to reducing these frictions.

Furthermore, we found that alternative real exchange rate measures, which are not based on CPI, and nonlinearities in the real exchange rate process carry useful additional market information. This allowed us to provide additional evidence that the real exchange rate follows an overall stationary, nonlinear process, which is indistinguishable from a random walk close to parity. As further integration of the world economy lets borders shrink further, the range of values assumed by the real exchange rate will shrink as well. Not matter how narrow the borders will eventually become, however, random walk behavior in the inner regime will ensure that reversion to PPP will still take a very long time.

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Table 1: Maximum Sustainable Imbalance ($\overline{\omega}$) as a Function of Risk and Risk Aversion for Low Relocation Cost ($r = 0.82$)

Risk av.	Risk (σ)					
$(1-\gamma)$	0^+	0.02	0.1	0.5	1	∞
0	∞	∞	∞	∞	∞	∞
0.1	7.305	n.a.	9.615	14.903	17.793	20.263
0.2	2.703	2.996	3.917	6.765	7.929	8.633
0.5	1.488	1.719	2.470	4.183	4.539	4.694
1	1.220	1.453	2.157	3.261	3.403	3.457
1.5	1.142	1.380	2.047	2.883	n.def.	2.965*
2	1.105	1.347	1.981	2.664	n.def.	2.700**

parameter values $\rho = 0.15$, $\alpha = 0.11$, $s = 1/1.22$

(* reported for $\sigma_{max} = 0.965$, ** reported for $\sigma_{max} = 0.674$)

Table 2: Maximum Sustainable Imbalance ($\overline{\omega}$) as a Function of Risk and Risk Aversion for High Relocation Cost ($r = 0.66$)

Risk av.	Risk (σ)					
$(1-\gamma)$	0^+	0.02	0.1	0.5	1	∞
0	∞	∞	∞	∞	∞	∞
0.1	57.665	n.a.	58.377	109.745	126.858	140.940
0.2	7.594	n.a.	10.598	17.181	20.284	22.494
0.5	2.250	2.578	3.642	6.773	7.782	8.305
1	1.500	1.784	2.701	4.876	5.341	5.544
1.5	1.310	1.602	2.463	4.216	n.def.	4.498*
2	1.225	1.540	2.350	3.852	n.def.	3.969**

parameter values $\rho = 0.15$, $\alpha = 0.11$, $s = 2/3$

(* reported for $\sigma_{max} = 0.935$, ** reported for $\sigma_{max} = 0.657$)

Table 3: Maximum Sustainable Imbalance in Asymmetric World as a Function of Risk Aversion for High Relocation Cost ($r = 0.66$)

Risk av. $(1-\gamma)$	Productivity $\alpha = \alpha^*$ $\overline{\omega}$	Productivity $\alpha > \alpha^*$ $\overline{\omega}$	$1/\underline{\omega}$
0.2	17.18	20.44	14.37
0.5	6.77	7.52	6.07
1	4.88	5.24	4.54
1.5	4.22	4.46	4.00
2	3.85	4.02	3.67

parameter values $\rho = 0.15$, $\alpha = 0.11$, $\alpha^* = 0.10$, $\sigma_{11} = \sigma_{22} = 0.5$, $\sigma_{12} = 0$, $s = 2/3$

Table 4: ESTAR Estimation Result

	inner regime		total
outer regime	stationary	nonstationary	153
stationary (AR)	36	98	134
nonstationary (AR)	5	14	19
stationary (AR $\times\Phi$)	40	112	152

Table 5: Indirect Inference Estimates, Real Exchange Rate based on WPI, Selected Countries

		γ	r	α	α^*	σ	q
France	Germany	-0.030	**0.855**	0.113	0.118	0.290	0.524
		(0.029)	**(0.024)**	(0.004)	(0.000)	(0.001)	(0.000)
France	Japan	-0.475	**0.765**	0.089	0.089	0.509	0.503
		(0.035)	**(0.031)**	(0.002)	(0.000)	(0.034)	(30.548)
France	UK	-0.043	**0.870**	0.018	0.073	0.629	0.670
		(1.843)	**(0.016)**	(0.060)	(0.466)	(0.531)	(1.649)
France	USA	0.394	**0.697**	0.042	0.110	0.558	0.573
		(0.486)	**(0.087)**	(0.037)	(0.037)	(0.045)	(0.336)
Germany	Japan	-0.639	**0.845**	0.456	0.383	0.638	0.537
		(1.207)	**(0.005)**	(0.660)	(0.823)	(0.263)	(0.159)
Germany	UK	-0.440	**0.861**	0.164	0.169	0.517	0.558
		(1.271)	**(0.005)**	(0.084)	(0.141)	(0.159)	(0.438)
Germany	USA	-0.495	**0.847**	0.112	0.121	0.504	0.499
		(0.020)	**(0.001)**	(0.004)	(0.005)	(0.019)	(0.004)
Japan	UK	-0.513	**0.664**	0.126	0.083	0.488	0.337
		(0.013)	**(0.032)**	(0.260)	(0.456)	(0.211)	(0.146)
Japan	USA	-0.126	**0.730**	0.010	0.010	0.532	0.801
		(1.476)	**(0.041)**	(0.107)	(0.256)	(0.370)	(0.661)
UK	USA	-0.282	**0.844**	0.060	0.048	0.590	0.520
		(0.899)	**(0.005)**	(0.459)	(0.593)	(0.236)	(0.679)

Inflation-adjusted bookvalues, demeaned, 1974:12–2007:06. ESTAR as auxiliary model with $p \leq 3$ and $d \leq 12$ chosen by nonlinearity test. Standard errors in parentheses.

Table 6: Indirect Inference Estimates, Real Exchange Rate based on Capital Goods, Selected Countries

Country	Country	Structural Parameter					
		γ	r	α	α^*	σ	q
France	Germany	-0.501	**0.526**	0.095	0.101	0.503	0.468
		(0.056)	**(0.000)**	(0.088)	(0.130)	(0.000)	(5.420)
France	Japan	-0.496	**0.497**	0.098	0.094	0.506	0.507
		(0.009)	**(0.028)**	(0.002)	(0.004)	(0.007)	(51.275)
France	UK	-0.208	**0.734**	0.069	0.054	0.665	0.505
		(0.020)	**(0.022)**	(0.011)	(0.001)	(0.012)	(0.014)
France	USA	-0.514	**0.681**	0.145	0.120	0.493	0.519
		(0.602)	**(0.010)**	(0.022)	(0.017)	(0.019)	(0.036)
Germany	Japan	-0.396	**0.620**	0.194	0.152	0.586	0.495
		(0.014)	**(0.017)**	(0.008)	(0.008)	(0.006)	(0.020)
Germany	UK	-0.597	**0.571**	0.135	0.144	0.473	0.917
		(0.494)	**(0.020)**	(0.006)	(0.009)	(0.002)	(0.778)
Germany	USA	-0.417	**0.638**	0.078	0.091	0.508	0.411
		(0.024)	**(0.018)**	(0.006)	(0.006)	(0.016)	(1.909)
Japan	UK	0.137	**0.427**	0.211	0.135	0.648	0.178
		(0.096)	**(0.017)**	(0.058)	(0.081)	(0.177)	(0.136)
Japan	USA	-0.020	**0.439**	0.140	0.180	0.421	0.667
		(0.005)	**(0.006)**	(0.009)	(0.001)	(0.003)	(0.004)
UK	USA	-0.205	**0.771**	0.139	0.116	0.765	0.252
		(0.067)	**(0.012)**	(0.014)	(0.021)	(0.021)	(4.586)

Inflation-adjusted bookvalues, demeaned, 1974:12–2007:06. ESTAR as auxiliary model with $p \leq 3$ and $d \leq 12$ chosen by nonlinearity test. Standard errors in parentheses.

Table 7: Border Effect, Comparison of Commodities with Capital Goods

		r_{WPI}	r_{CAP}	$\frac{1-r_{CAP}}{1-r_{WPI}}$
France	Germany	0.855	0.526	3.27
		(0.024)	(0.000)	
France	Japan	0.765	0.497	2.14
		(0.031)	(0.028)	
France	UK	0.870	0.734	2.05
		(0.016)	(0.022)	
France	USA	0.697	0.681	1.06
		(0.087)	(0.010)	
Germany	Japan	0.845	0.620	2.45
		(0.005)	(0.017)	
Germany	UK	0.861	0.571	3.09
		(0.005)	(0.020)	
Germany	USA	0.847	0.638	2.37
		(0.001)	(0.018)	
Japan	UK	0.664	0.427	1.71
		(0.032)	(0.017)	
Japan	USA	0.730	0.439	2.08
		(0.041)	(0.006)	
UK	USA	0.844	0.771	1.47
		(0.005)	(0.012)	

Inflation-adjusted bookvalues, demeaned, 1974:12–2007:06. ESTAR as auxiliary model with $p \leq 3$ and $d \leq 12$ chosen by nonlinearity test. Standard errors in parentheses.

Table 8: Width of the Border with vs. USA

Commodities	γ	r	Capital Goods	γ	r
Canada	0.268	0.938	Italy	-0.498	0.858
	(0.023)	(0.002)		(0.003)	(0.001)
Belgium	-0.191	0.922	Switzerland	-0.500	0.846
	(0.000)	(0.010)		(0.043)	(0.005)
Austria	-0.233	0.903	**UK**	-0.205	0.771
	(0.087)	(0.008)		(0.067)	(0.012)
Denmark	-0.185	0.899	Netherlands	-0.263	0.752
	(0.606)	(0.011)		(0.004)	(0.009)
Switzerland	-0.031	0.874	Norway	-0.593	0.738
	(0.570)	(0.010)		(0.053)	(0.036)
Singapore	0.110	0.873	Belgium	-0.255	0.732
	(0.288)	(0.023)		(0.072)	(0.010)
Australia	-0.237	0.862	Denmark	-0.498	0.719
	(1.562)	(0.007)		(0.029)	(0.011)
Norway	-0.010	0.861	France	-0.514	0.681
	(0.488)	(0.007)		(0.602)	(0.010)
Germany	-0.495	0.847	Sweden	-0.014	0.645
	(0.020)	(0.001)		(0.118)	(0.084)
Netherlands	-0.218	0.845	**Germany**	-0.417	0.638
	(0.352)	(0.010)		(0.024)	(0.018)
UK	-0.282	0.844	**Canada**	0.768	0.631
	(0.899)	(0.005)		(0.062)	(0.003)
Sweden	-0.077	0.835	Australia	-0.255	0.613
	(1.073)	(0.037)		(0.223)	(0.030)
Spain	0.326	0.813	Austria	-0.192	0.561
	(3.184)	(0.016)		(0.198)	(0.033)
Hongkong	-0.146	0.786	Spain	-0.549	0.501
	(0.014)	(0.018)		(0.018)	(0.031)
Italy	0.143	0.750	Hongkong	-0.207	0.498
	(0.693)	(0.025)		(0.027)	(0.008)
Japan	-0.126	0.730	**Japan**	-0.020	0.439
	(1.476)	(0.041)		(0.005)	(0.006)
France	0.394	0.697	Singapore	-0.270	0.372
	(0.486)	(0.087)		(0.018)	(0.027)

Inflation-adjusted bookvalues, demeaned, 1974:12–2007:06. ESTAR as auxiliary model with $p \leq 3$ and $d \leq 12$ chosen by nonlinearity test. Standard errors in parentheses.

Table 9: Components of Relocation Cost

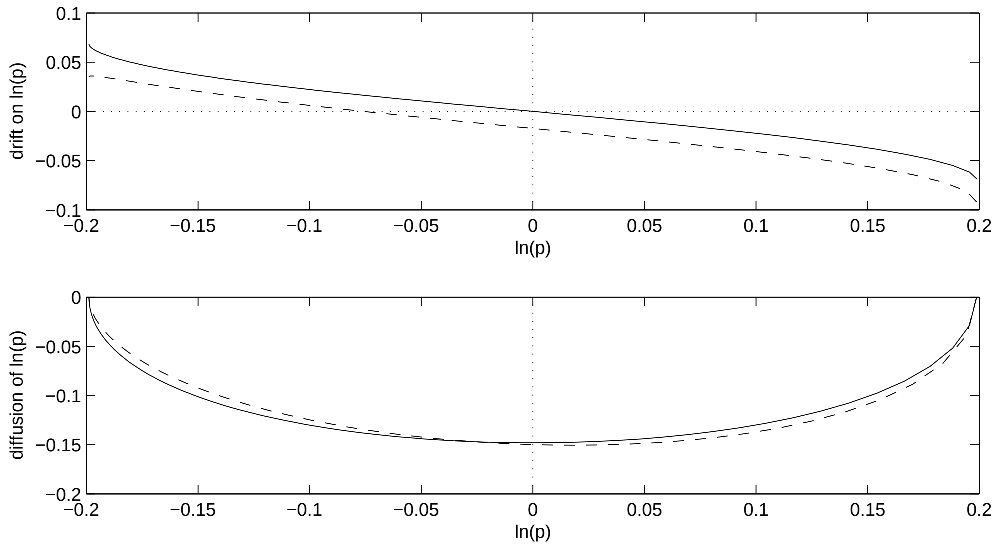
	$log(r_{WPI})$			$log(r_{CAP})$	
	(1)	(2)	(3)	(1)	(3)
Distance	-0.0767	-0.0862**	-0.0801*	0.0221	-0.251**
	(0.0526)	(0.0363)	(0.0416)	(0.117)	(0.116)
Large country GDP	0.0579***	0.0566***	0.0561***	0.0938*	0.0593
	(0.0185)	(0.0160)	(0.0164)	(0.0499)	(0.0438)
Sum of GDPs	-0.0594***	-0.0559***	-0.0551***	-0.0823	-0.0479
	(0.0194)	(0.0162)	(0.0167)	(0.0521)	(0.0446)
Common language	0.023			-0.241*	
	(0.060)			(0.129)	
# Mergers	1.78e-5			1.58e-4*	
	(3.33e-5)			(0.81e-4)	
Europe ex. UK			0.021		-0.275*
			(0.065)		(0.143)
Constant	-0.062	-0.061	-0.071	-0.572***	-0.325**
	(0.047)	(0.044)	(0.056)	(0.081)	(0.155)
Adj. R^2	0.334	0.340	0.312	0.127	0.135
N	26	26	26	32	32

Dependent variable: $ln(r)$, independent variables: distance (in 10000 km), GDP of the larger country (trillion USD at PPP, 2003), sum of GDP of both countries (trillion USD at PPP, 2003), number of mergers between firms located in either of the two countries in 2003. Standard errors in parentheses. (* significant at the 10% level, ** at 5% level, *** at 1% level)

Table 10: “Glacial” hittimes, Example Germany-USA

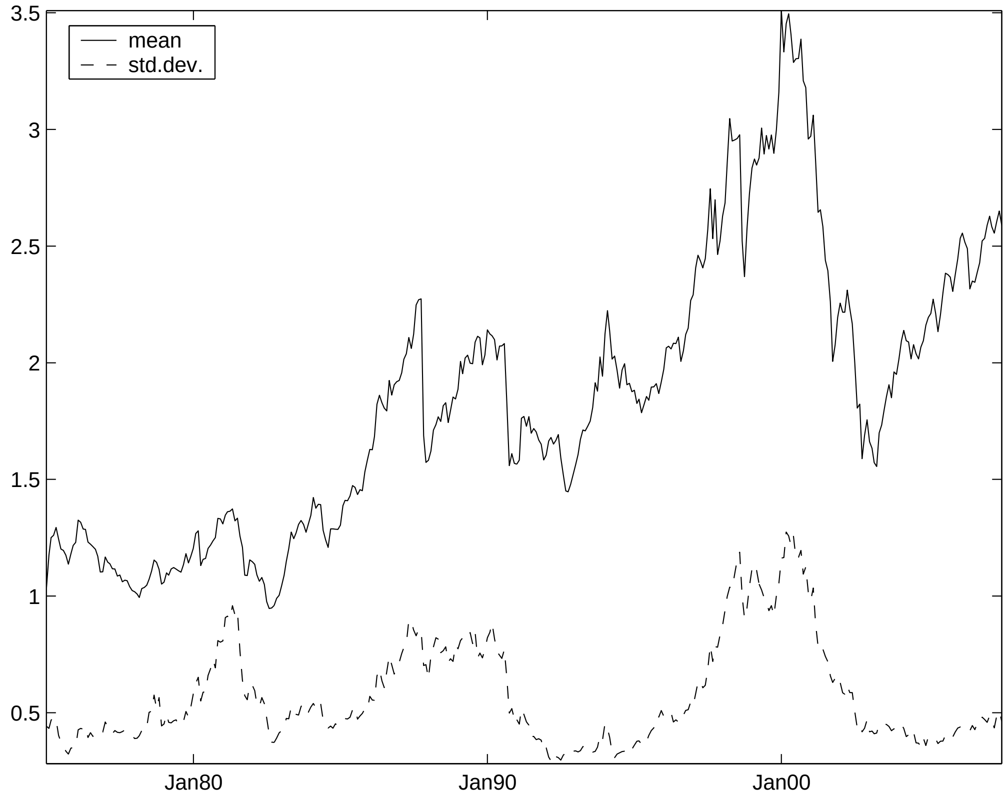
	consumption goods	capital goods
Hit of a boundary starting at parity	5.1 years	13.7 years
Hit of parity starting at $\overline{\omega}$	4.8 years	11.2 years
Hit of parity starting at $\underline{\omega}$	7.3 years	20.8 years

Figure 1: Drift and Diffusion of Price Process, Countries Differing by Productivity Mean



The upper panel shows the drift of the natural logarithm of the real exchange rate process as a function of the natural logarithm of the current real exchange rate, $ln(p)$. The lower panel shows the corresponding diffusion. The solid line shows the process for the case when both countries are identical ($\alpha = 0.11$, $\alpha^* = 0.11$). The dashed line obtains if country 2 has a lower productivity than country 1 ($\alpha = 0.11$, $\alpha^* = 0.05$). The other parameter values used for this graph are $\gamma = 0.5$, $\rho = 0.15$, $r = 0.82$, $\sigma_{11} = 0.5$, $\sigma_{12} = 0$, and $\sigma_{22} = 0.5$. The range of imbalances sustainable at these parameter values is $\omega \in [0.24, 4.18]$.

Figure 2: Average and Standard Deviation of Market-to-Book Ratios Across Countries



The graph shows the equal-weight mean and standard deviation of the market-to-book value for all 153 country pairs for the period 1974:12-2007:06.

Figure 3: Book Value Correction, Germany (local currency)

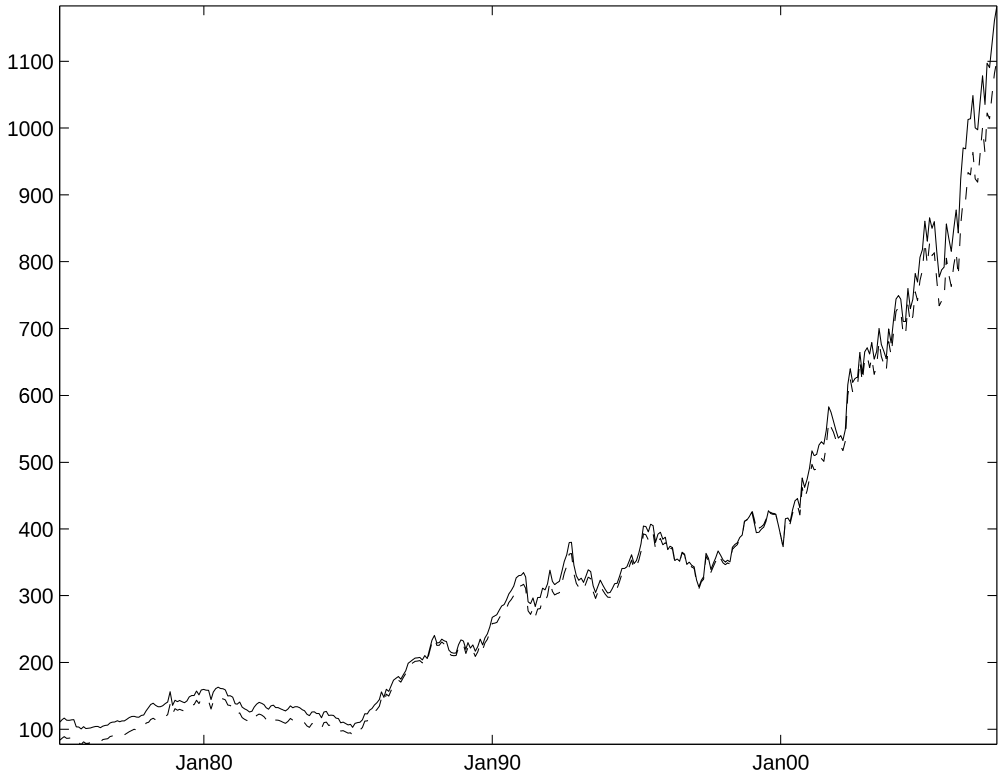


Figure 4: Real Exchange Rate based on Capital Goods, Germany – USA

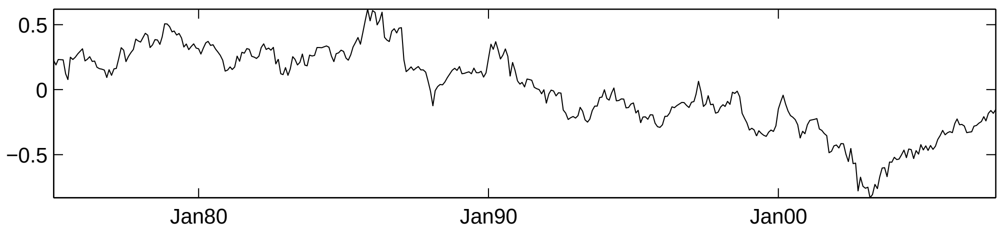


Figure 5: Real Exchange Rates: Germany–USA

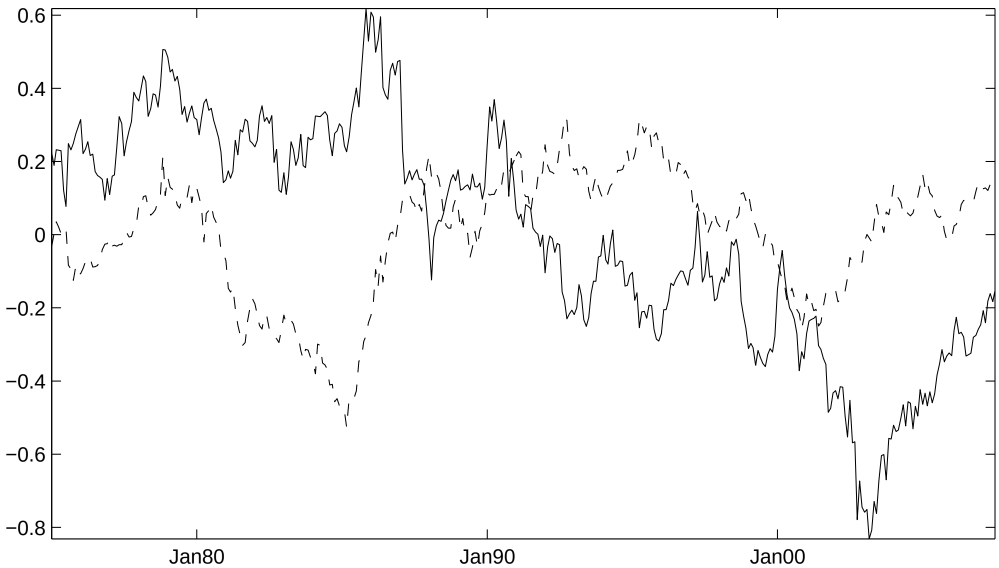


Figure 6: Real Exchange Rates: Canada–USA

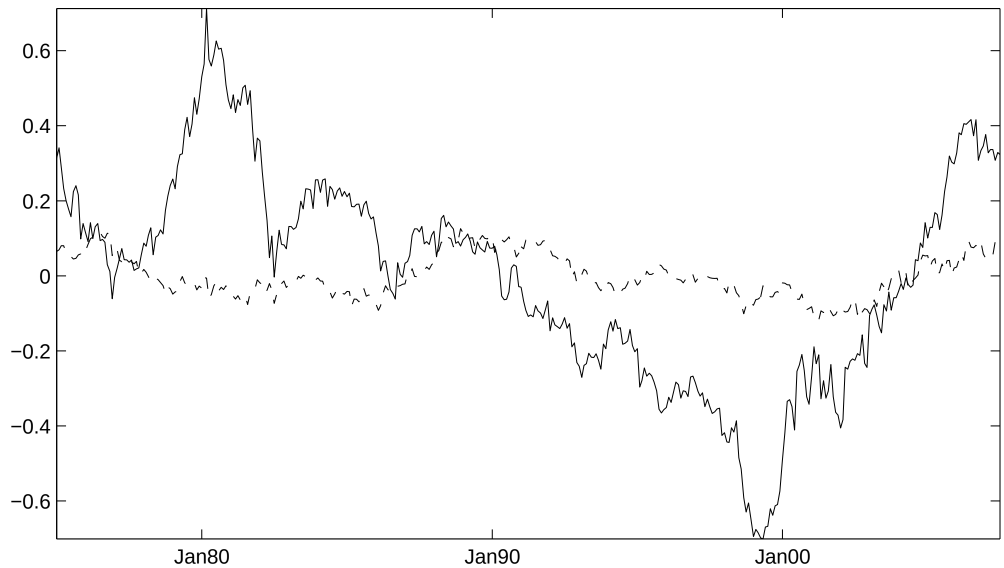


Figure 7: Real Exchange Rates: Japan–USA

Figure 8: Real Exchange Rates: UK–USA

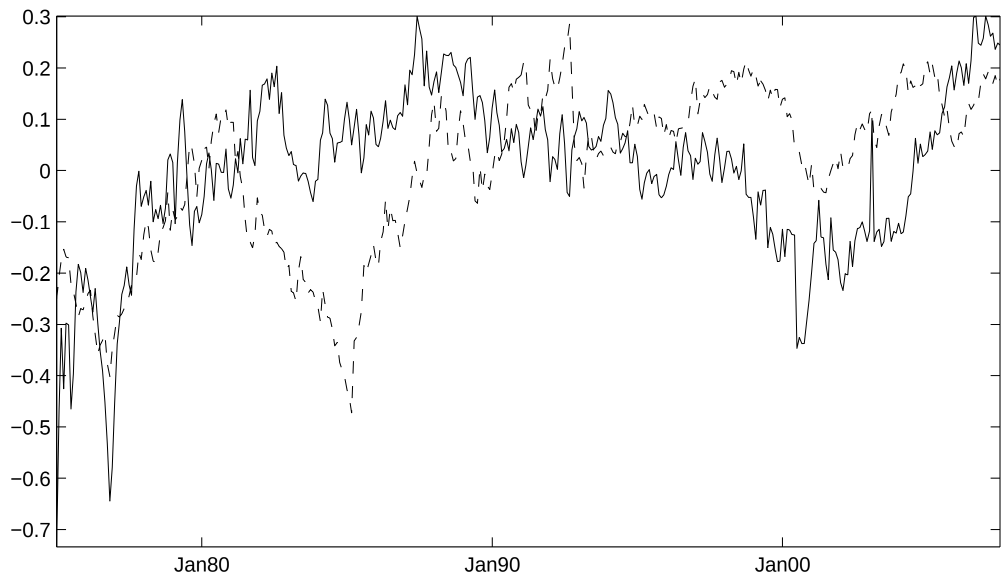


Figure 9: 24-month Changes in Real Exchange Rate of Capital Goods vs. Initial Levels, Canada – USA

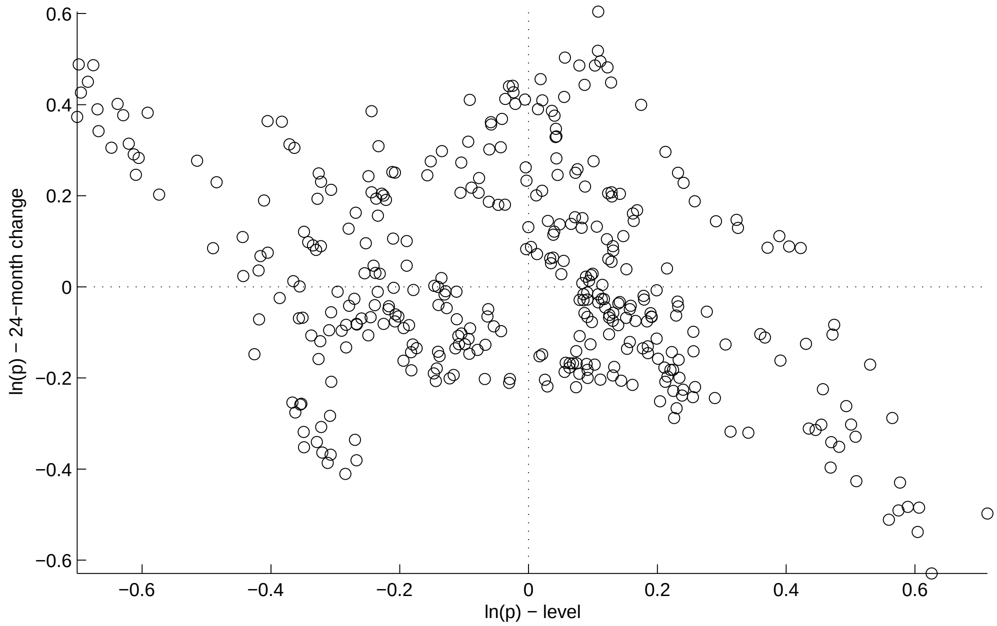


Figure 10: 24-month Changes in Real Exchange Rate of Capital Goods vs. Initial Levels, Germany – USA

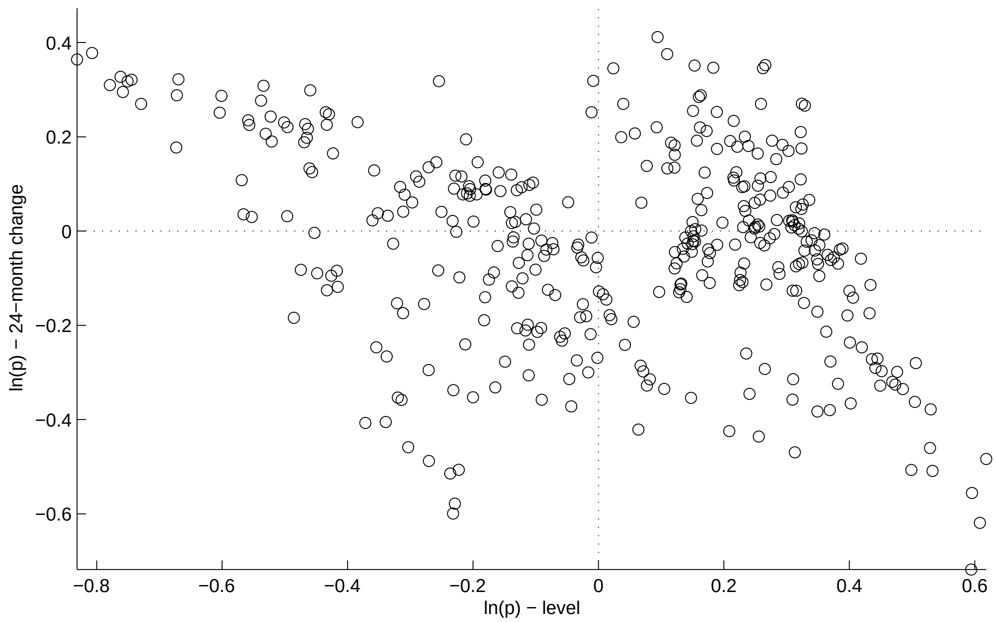
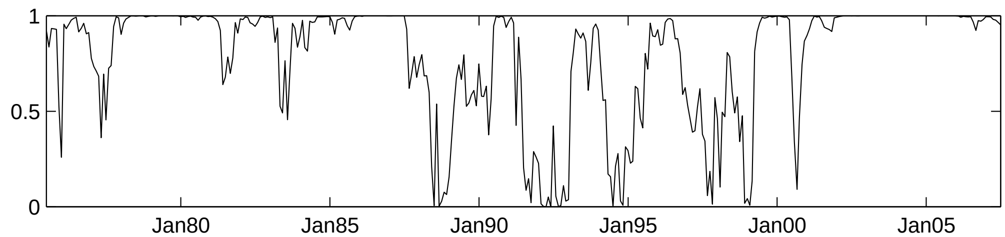
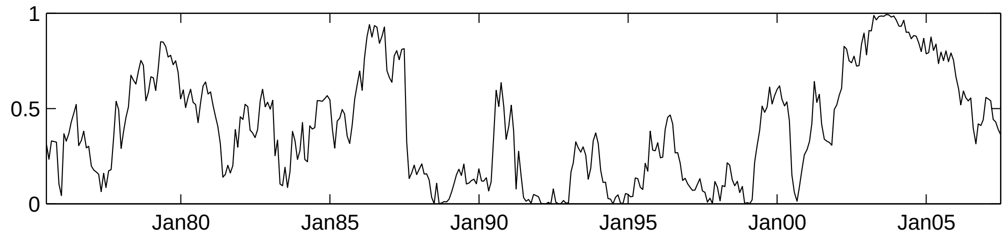


Figure 11: Time Variation of Transition Function of Mean, Germany – USA



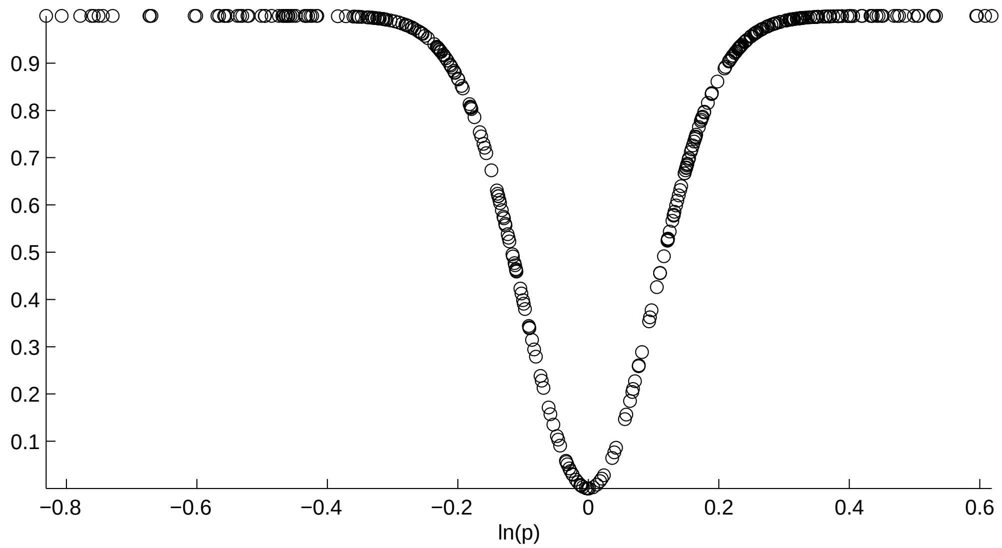
The graph plots the values the ESTAR transition function of the conditional mean for the country pair Germany–USA during the period 1974:12–2007:6.

Figure 12: Time Variation of Transition Function of Variance, Germany – USA



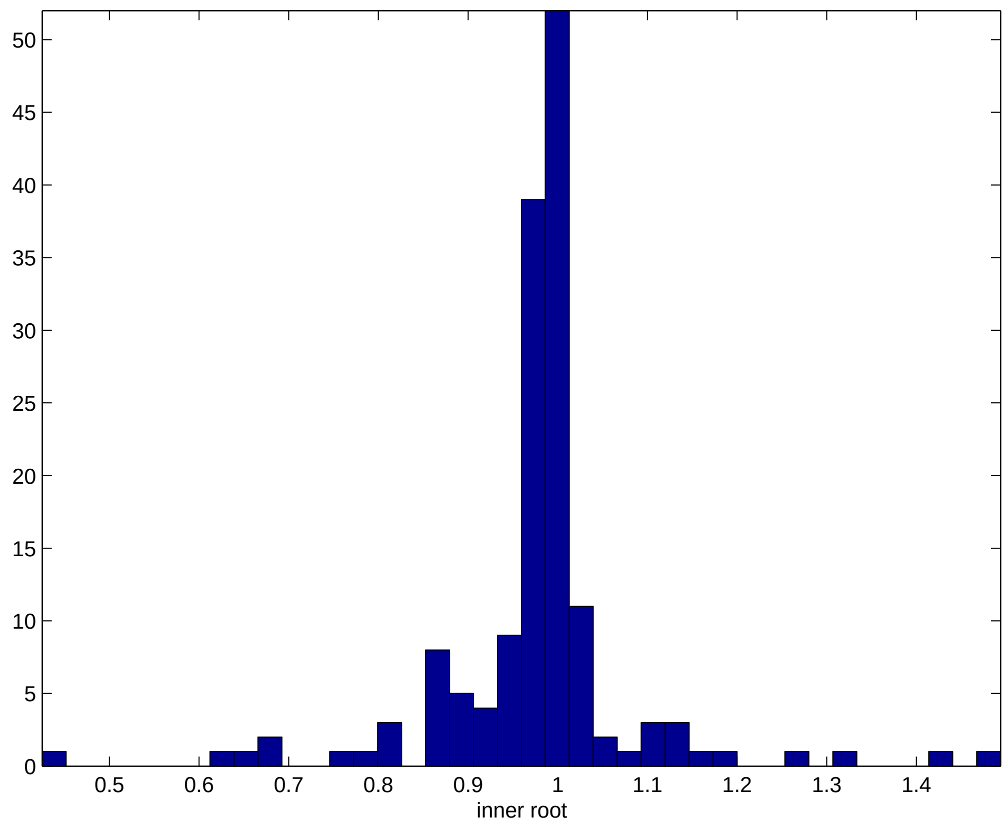
The graph plots the values of the ESTAR transition function of the conditional variance for the country pair Germany–USA during the period 1974:12–2007:6.

Figure 13: Transition Function of Mean, Germany – USA



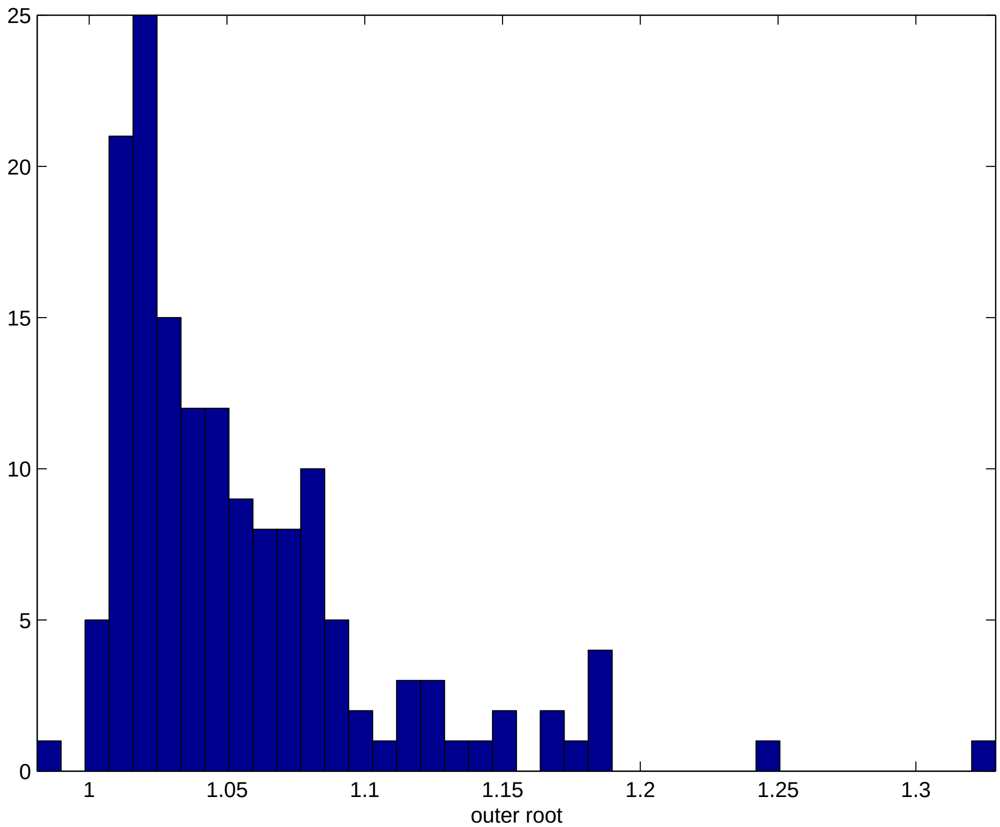
The graph shows the ESTAR transition function for Germany-USA. Each dot represents on time observation during 1974:12–2007:6.

Figure 14: Frequency Distribution of Root of Inner Regime



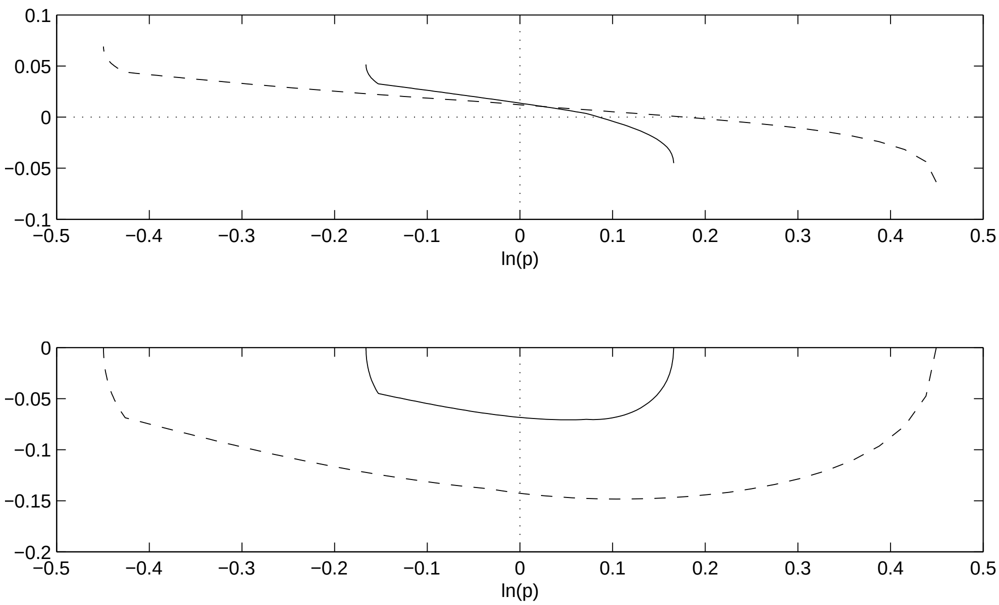
The histogram shows the frequency distribution of the root of the inner regime based on ESTAR estimates for all 153 country pairs during the period 1974:12–2007:6.

Figure 15: Frequency Distribution of Root of Outer Regime



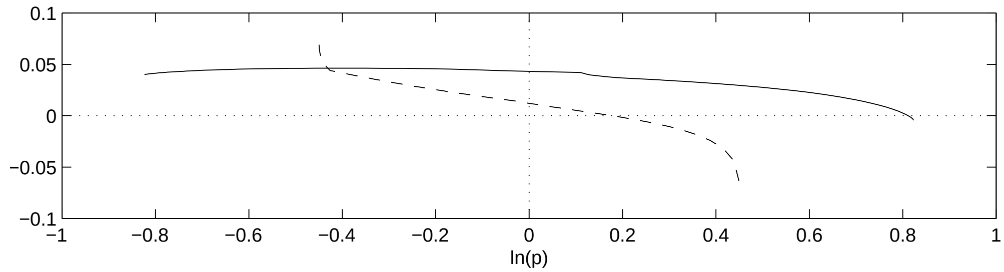
The histogram shows the frequency distribution of the root of the outer regime based on ESTAR estimates for all 153 country pairs during the period 1974:12–2007:6.

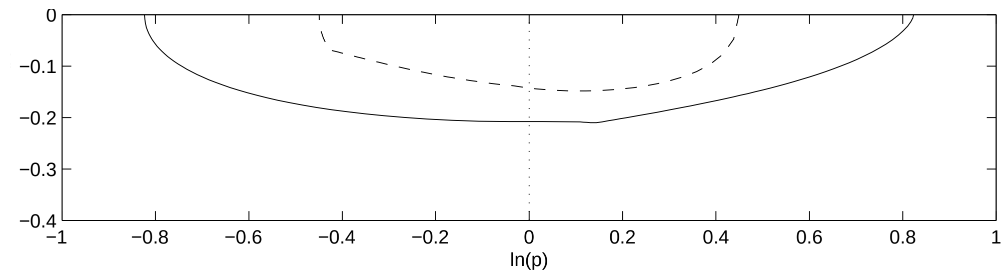
Figure 16: Germany – USA, Estimated Drift and Diffusion, Commodities vs. Capital Goods



The graph plots the estimated drift and diffusion of the real exchange rate process, based on commodities (solid line) and based on capital goods (dashed line), for the pair Germany-USA during the period 1974:12–2007:6. Parameter values are taken from tables 5 and 6. The range of sustainable imbalances for commodities is $\omega \in [0.37; 2.23]$, and for capital goods $\omega \in [0.17; 3.81]$.

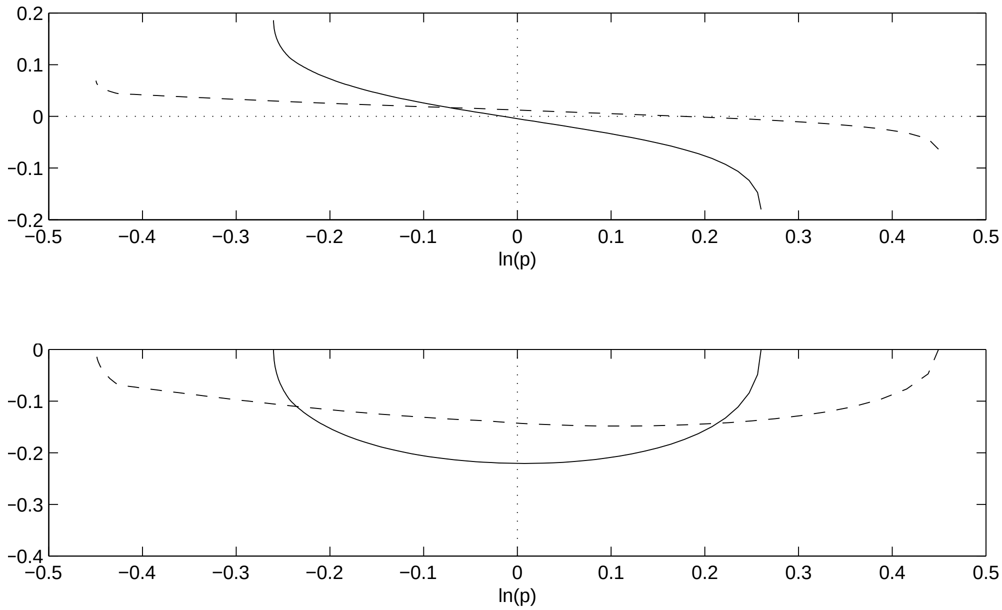
Figure 17: Japan – USA, Drift and Diffusion of Real Exchange Rate based on Capital Goods





The solid line is the estimated drift and diffusion of the real exchange rate of capital goods for the country pair Japan – USA during the period 1974:12–2007:6. The dashed line plots the same for Germany-USA. Parameter values are taken from tables 5 and 6. The range of sustainable imbalances is $\omega \in [0.02; 2.27]$.

Figure 18: UK – USA, Drift and Diffusion of Real Exchange Rate based on Capital Goods



The solid line is the estimated drift and diffusion process for the country pair UK – USA during the period 1974:12–2007:6. The dashed line plots the same for Germany-USA. Parameter values are taken from tables 5 and 6. The range of sustainable imbalances is $\omega \in [0.32; 4.39]$.

Figure 19: Transfer Costs of Commodities vs. Relocation Costs of Capital Goods

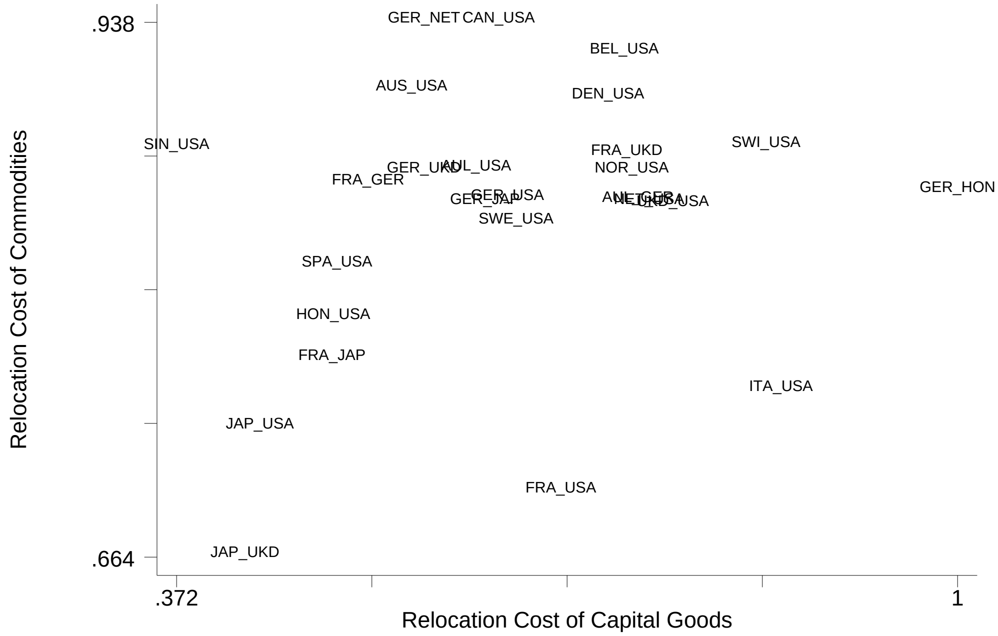
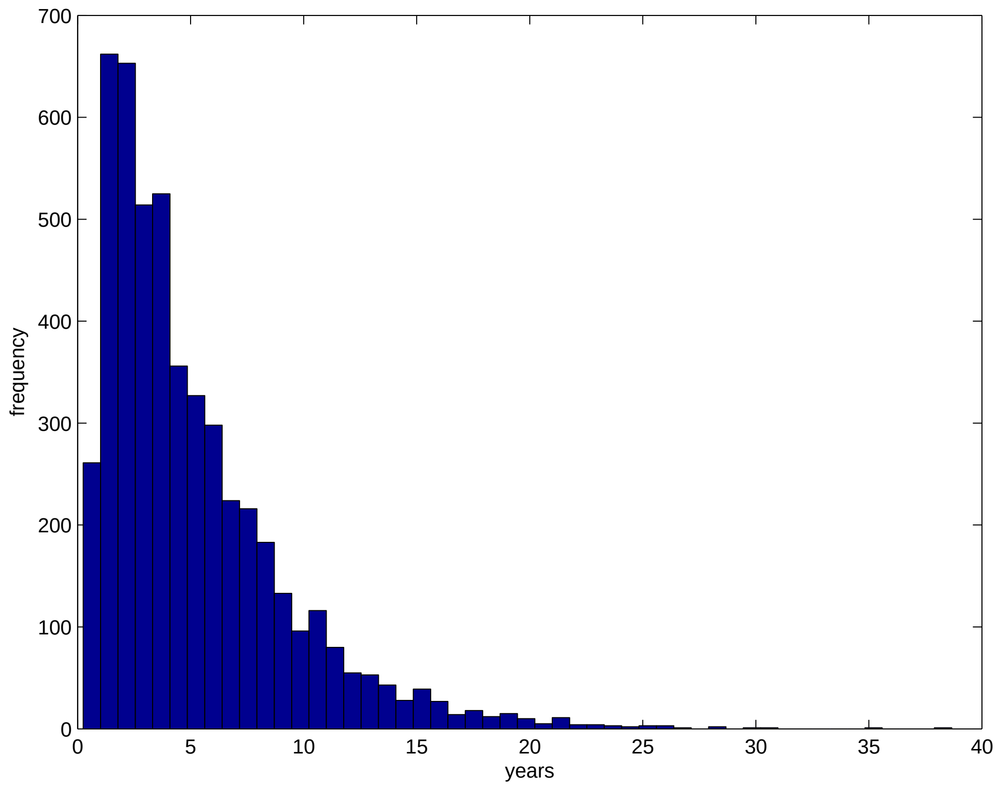
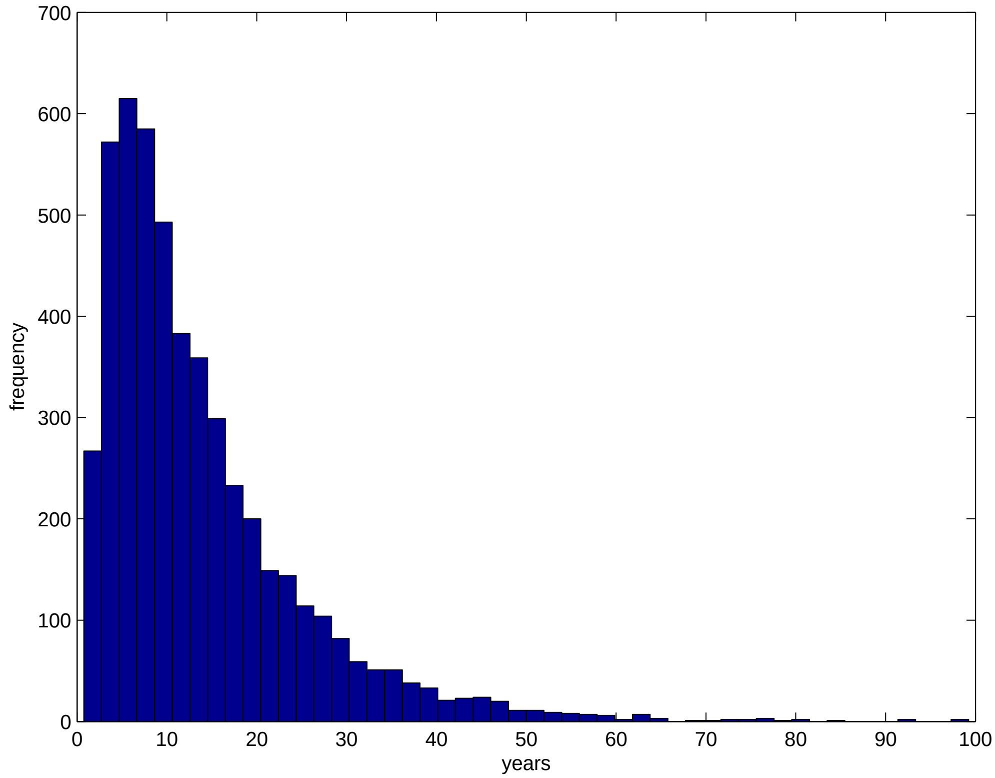


Figure 20: Hittime Distribution for Commodities, Germany–USA



The histogram shows the distribution of the time span until the price process hits one of the boundaries for the first time, when the process starts from a balanced position ($p(0) = 0$). The histogram is based on 5000 simulated sample paths with parameter values taken from table 5.

Figure 21: Hittime Distribution for Capital Goods, Germany–USA



The histogram shows the distribution of the time span until the price process hits one of the boundaries for the first time, when the process starts from a balanced position ($p(0) = 0$). The histogram is based on 5000 simulated sample paths with the parameter values taken from table 6.