The Efficiency of the Global Markets for Final Goods and Productive Capabilities*

Georg Strasser@
Boston College

This Draft: August 15, 2010

Abstract

Despite integration of financial and goods markets, borders still impose considerable friction on the flow of goods. This paper shows that a decline in output shock variance might increase the time of mean reversion despite declining border frictions. We estimate these frictions and determinants of mean reversion using a novel measure of the real exchange rate for productive capabilities. Our estimate of border cost builds on nonlinearities in the real exchange rate process. We find large cost differences between relocating final goods and productive capabilities. During the years 1974–2008, a relocation reduces productive capability by 18% for the median country pair, whereas final goods by only 13%.

Keywords: Border effect, Capital goods, Indirect inference, Real exchange rate, PPP, Technology Spillover, Threshold model
JEL classification: F21, F31, C51

*For comments and suggestions I thank Frank Diebold, Bernard Dumas, Urban Jermann, Karen Lewis, and Frank Schorfheide, and seminar participants at Boston College, Erasmus Universiteit Rotterdam, Georgetown University, the University of North Carolina at Chapel Hill, Purdue University, Università Bocconi, University of Pennsylvania, CEMFI, the Oxford-Man Institute of Quantitative Finance, the Bank of Canada, the European Central Bank, the Board of Governors of the Federal Reserve System, and at the Federal Reserve Bank of New York.

@Department of Economics, Boston College, 140 Commonwealth Avenue, Chestnut Hill, MA 02467-3806, +1.617.552.1954 (*Georg.Strasser@bc.edu*)

1 Introduction

During the last three decades not only final goods, but also capital goods, have become increasingly mobile. Despite globalization of financial and goods markets borders constitute a considerable friction for flows of goods. The extent of these frictions varies considerably: For final goods, on the one hand, frictions may be limited to plain transportation costs. For capital goods, on the other hand, frictions may comprise a very complex relocation if the good needs to be adapted to the local environment or if its use requires training. Differences in standards, culture, skill, and local technology levels bring about relocation costs that far exceed the cost of transportation.

Previous studies of the market frictions embodied in borders focus on *final goods*. These goods are similarly useful in all countries and do not require an excessive amount of localization, which is why we also refer to them as *unbundled goods*. Existing estimates of market frictions rely on trade flows (e.g. McCallum 1995, Anderson & van Wincoop 2003) and on the real exchange rate of consumer goods (e.g. Broda & Weinstein 2008, Engel & Rogers 1996, Gorodnichenko & Tesar 2009). No estimates exist, however, of the relocation costs of more complex goods, such as capital goods or *productive capabilities*. Productive capabilities comprise, for example, machinery, technology, and human capital embedded in the productive sector.

Markets for productive capabilities deserve particular attention, as international flows of final goods are largely liberalized. The cost of adjusting productive capability by means of investing, i.e. the cost of converting final goods into productive capabilities and vice versa, is considerable, and unbundling and rebundling of productive capabilities for the sole purpose of relocating them is usually economically unfeasible. Thus the cost of *directly* relocating productive capabilities becomes decisive for the efficiency of their global allocation. This allocation is a key determinant of relative output and ultimately of relative welfare. Unsurprisingly, it is an enduring core issue of international economics (Lucas 1990, Hsieh & Klenow 2007).

Several key questions emerge: How costly is the relocation of productive capabilities? Does this cost differ by country pair, and what share of this cost can be attributed to national borders? How do these relocation costs relate to the cost of transferring final goods? The answer to each of these questions has direct implications for relative market efficiency and for determining which market would most benefit from additional effort to reduce these frictions.

A natural approach to these questions might start with data on goods' allocations among countries, which is available unfortunately only as a rough estimate, especially for productive capabilities. We therefore choose an indirect approach. Dumas (1992), as well as Sercu, Uppal & van Hulle (1995), formally derive the link between relocation cost, allocations of goods and the real exchange rate.[1] As already observed by Heckscher (1916), under non-zero relocation cost large deviations from purchasing power parity (PPP) can persist. 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 them.

Because the conventional definition of a real exchange rate is based on the price index for unbundled goods, e.g. the consumer (CPI) or wholesale price index (WPI), its behavior over time reflects the frictions in the market for unbundled goods. Such a real exchange rate contains no information on productive capabilities. For this reason, we construct a novel measure of the real exchange rate based on productive capabilities, which allows us to compare productive capabilities with final goods.

An important innovation of our approach is the estimation of relocation cost directly from the variation of the real exchange rate over time. Unlike previous studies, we do not rely exclusively on differences of price index levels between countries. Instead, we build on continuous time models of international finance, which predict more than just bounds on sustainable price differences between two countries. Rather, their solution provides the entire real exchange rate process, in particular the evolution of drift and diffusion over time. Our model, similar to Dumas (1992), predicts that both the conditional drift and diffusion follow a nonlinear process. A parsimonious approximation, which captures this nonlinearity, is the exponential smooth transition autoregressive (ESTAR) model. We utilize ESTAR as a natural auxiliary model in an indirect inference framework, which allows us to translate nonlinearity into relocation costs.

We build on several strands of earlier literature. First, nonlinearity in real exchange rates is a well-documented phenomenon.[2] Prakash & Taylor (1997) and Obstfeld & Taylor (1997), for example, estimate a model with a hard cut-off between regimes.[3] Closer to our approach

[1] Costs of international trade have also been included in international business cycle models, e.g. Backus, Kehoe & Kydland (1992), Obstfeld & Rogoff (2001), and Ravn & Mazzenga (2004).

[2] The importance of a nonlinear specification is highlighted by the weak support for mean-reversion achievable with linear models (Adler & Lehman 1983, Frankel & Rose 1996, Lothian & Taylor 1996, Rogoff, Froot & Kim 2001). Froot & Rogoff (1995) and Sarno (2005) provide useful surveys. These studies imply extremely slow overall speeds of mean reversion (Rogoff 1996, Murray & Papell 2005). Nonlinear models provide a natural explanation for both observations. The real exchange rate mean-reverts whenever it has wandered far away from parity, but follows a random walk when it is close to parity.

[3] This threshold autoregressive model was introduced by Tong (1990) and Balke & Fomby (1997).

are studies that use a smooth transition between regimes, as in the ESTAR specification.[4] Michael, Nobay & Peel (1997), for example, use a sample of monthly WPI data of four countries in the 1920s and annual data for two countries over 200 years. Taylor, Peel & Sarno (2001) work with monthly CPI data for five countries over the period 1973–1996. Modeling real exchange rates by an ESTAR model, Kilian & Taylor (2003) find predictability of the nominal exchange rate at horizons of two years or more. All these studies report strong support for a nonlinear specification, with a random walk dominating over short horizons. However, these studies do not make further use of this nonlinearity to quantify the relocation cost, nor are their results applicable to productive capabilities.

Second, our work is related to studies of mean reversion of international stock markets. Studies focusing on relative nominal international stock prices, such as Richards (1995) and Balvers, Wu & Gilliland (2000), find evidence of transitory country-specific effects in long-run relative stock returns. No one has yet explored the mean reversion of a real capital market-based measure, such as the real exchange rate for productive capabilities.

Third, Caselli & Feyrer (2007) show the importance of price of and availability of complementary factors, such as technology (Eaton & Kortum 1999) or human capital (Lucas 1990), for differences in the marginal product of capital across countries. Because our definition of productive capabilities contains these complementary factors, our estimates of border cost shed light on the causes of sustained country heterogeneity in stocks of these factors.

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 empirical results, and section 5 concludes.

2 Methodology

In this section we first discuss a model of endogenous capital accumulation with depreciation shocks and relocation cost, which captures key features of the real exchange rate data. We then derive a novel measure of the real exchange rate of productive capabilities, and compare its properties with a conventional real exchange rate series.

[4]See Taylor (2005) for a survey. At the sectoral level, Imbs, Mumtaz, Ravn & Rey (2003) find nonlinearity for two thirds of the sectors in their sample.

2.1 Modeling Real Exchange Rates with Frictions

In the following we lay out a model of a particular segment of a two-country economy subject to arbitrage trade.[5]

We assume complete financial markets, i.e. all necessary securities are available and international financial flows are unconstrained.[6] The counterpart of financial markets in the real economy, the market for goods, is subject to frictions. Relocating a generic good from one country to another entails a cost, $1 - r \in (0, 1)$, that is, of every unit relocated only r percent arrive. Specifically, if, on the one hand, we interpret the model in terms of final goods, then this cost reflects first and foremost the cost of shipping. If, on the other hand, we interpret the model in terms of productive capabilities, then r contains a second component: the cost of relocating organizational structures and knowledge necessary for operating the physical good. The overall relocation cost for productive capabilities can therefore be higher than for final goods, even if the shipping cost for productive capabilities is small.

Our model economy consists of two countries, which are separated by a border. There is only one good in our economy,[7] which we interpret as *either* a final good *or* a productive capability. Because any transfer of goods across the border entails an "iceberg" loss of $1-r$, the good's location matters.[8] 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 zero-mean depreciation shocks, $\sigma_{11}dz$ and $\sigma_{22}dz^*$, where dz and dz^* are increments of a standard Brownian motion process.[9]

The marginal rates of substitution differ between countries at almost every instance because of the cost of crossing the border. Because the relocation cost is the only friction hindering the movement of goods, this cost bounds the possible valuation differences between countries from above. No relative valuation 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 relative valuation has returned back into this interval.[10]

[5] See appendix A for a larger model that also embeds trade due to specialization.

[6] Completeness seems to accurately describe financial markets among developed countries over the past 30 years, considering the almost immeasurable variety of financial instruments. Between developed countries, movements of financial capital were largely free from legal restrictions. See e.g. Allen & Gale (1994).

[7] This rules out trade due to specialization or love-of-variety – only trade for arbitrage reasons is possible.

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

[9] A more general economy is described in appendix B.1.

[10] Obviously, the economy is always in equilibrium. Thus there is no "mispricing" of stocks or other assets which in some finance models constitutes an arbitrage opportunity that triggers e.g. foreign direct investment (Baker, Foley & Wurgler 2009) or investment (Polk & Sapienza 2009), or where imperfect capital markets

Owing to the assumption of complete financial markets, the decentralized two-country problem is equivalent to the planner's problem[11]

$$V(K,K^*) = \max_{\substack{c(t),c^*(t),\\ \Xi(r)}} E_0 \int_0^\infty e^{-\rho u}\left(\frac{q}{\gamma}c(u)^\gamma + \frac{2-q}{\gamma}c^*(u)^\gamma\right)du \tag{1}$$

s.t.

$$\begin{aligned} dK(t) &= [\alpha K(t) - c(t)]\,dt + K(t)\sigma_{11}dz(t) - dX(t) + r dX^*(t) \\ dK^*(t) &= [\alpha^* K^*(t) - c^*(t)]\,dt + K^*(t)\sigma_{22}dz^*(t) + r dX(t) - dX^*(t) \end{aligned}$$

where $K(0)$ and $K^*(0)$ are given, $c(t), c^*(t), K(t), K^*(t), X(t), X^*(t) \geq 0\ \ \forall t$, 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 $dX^* = 0$. Note that $\Xi(r)$ is chosen optimally, and thus dX and dX^* are endogenous. Due to the homogeneity of the value function, Ξ is fully characterized by the minimal and maximal imbalance levels, $\underline{\omega}$ and $\overline{\omega}$.[12]

The symmetric version of this model has been developed by Dumas (1992).[13] We extend this model by country heterogeneity in the ability to produce new goods (Hsieh & Klenow 2007), which can result in persistent price differences between countries. Making the model asymmetric complicates it considerably, but helps explaining key features of the real exchange rate, for example, a non-zero unconditional mean of its drift.

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

$$0 = \frac{1-\gamma}{\gamma}q^{\frac{1}{1-\gamma}}I'(\omega)^{\frac{\gamma}{\gamma-1}} + \frac{1-\gamma}{\gamma}(2-q)^{\frac{1}{1-\gamma}}\left[\gamma I(\omega) - \omega I'(\omega)\right]^{\frac{\gamma}{\gamma-1}}$$

cause foreign direct investment to be linked with e.g. currency movements (Froot & Stein 1991).

[11]Basak & 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 (1).

[12]Appendix B provides detailed calculations and discussion of many of the results in this section.

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

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

By optimal choice of the boundary of Ξ, the unknown function $I(\omega)$ must satisfy value matching and smooth pasting conditions at both boundaries at all times. The value matching condition requires equalization of the value of the marginal good at the moment of relocation, e.g. for the upper boundary, $\overline{\omega}$,[14]

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

The smooth pasting conditions require

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

and

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

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

$$
\frac{I'(\overline{\omega})}{\gamma I(\overline{\omega})} = \frac{r}{1 + r\overline{\omega}} \tag{3}
$$

$$
\frac{I''(\overline{\omega})}{\gamma I(\overline{\omega})} = \frac{r^2(\gamma-1)}{(1 + r\overline{\omega})^2} \tag{4}
$$

The differential equation (2) with boundary conditions (3) and (4) and the analogous conditions for the lower boundary can now 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 Bulirsch-Stoer method (Stoer & Bulirsch 2005) augmented by a Richardson extrapolation.[15] Richardson's deferred approach to the limit corrects for the estimated error stemming from finite accuracy. A solution has been found if the values of $(I'(\omega_0), I''(\omega_0))$ obtained by iterating from the upper boundary are equal to the values obtained by iterating from the lower boundary, i.e. if $\overline{I'(\omega_0)} = \underline{I'(\omega_0)}$ and $\overline{I''(\omega_0)} = \underline{I''(\omega_0)}$. Otherwise we retry with a new guess for the pair of

[14] The conditions for the lower boundary are analogous.

[15] Press, Teukolsky, Vetterling & Flannery (2001, p.718ff) describe this technique in detail.

boundaries. In a second step we use the results from the Bulirsch-Stoer method as starting values in a Newton algorithm for two point boundary value problems.[16]

[Table 1 about here.]

The upper panel of table 1 reports the maximum sustainable imbalance as a function of risk and risk aversion for modest relocation cost ($r = 0.9$) in a symmetric world. The imbalances are the larger, the lower the risk aversion and the higher the risk. The lower panel of the same table shows that a higher relocation cost ($r = 0.75$) implies larger sustainable imbalances for any level of risk aversion and risk. The corresponding hittimes, given in table 2, shoot up even more.

[Table 2 about here.]

The tables reveal that, given some 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. If two countries differed in their productivity, then the sustainable abundance of goods in the more productive country would be higher, and correspondingly lower in the less productive country.

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.

$$p(\omega) = \frac{V_K(K, K^*)}{V_{K^*}(K, K^*)} = \frac{I'(\omega)}{\gamma I(\omega) - \omega I'(\omega)}. \quad (5)$$

Note that the real exchange rate depends only on the imbalance, ω, but not on the stocks, K and K^*, themselves. Therefore, the real exchange rate tracks the *relative* scarcity of goods – a scarcity due to the frictions in the goods market, which emphasizes the strong impact of relative productivity on the real exchange rate.

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

$$dln(p) = \mu_p(p)dt + \sigma_p(p)dz$$

[16] Press et al. (2001, p.376ff) present a similar algorithm. This second step improves precision. Whereas this Newton algorithm is very effective in fine-tuning a raw solution, it cannot be recommended as a stand-alone routine. Without Bulirsch-Stoer as a first step, the Newton algorithm would frequently fail to find the solution.

can be written as a function of ω, $I(\omega)$, $I'(\omega)$, $I''(\omega)$. The drift of $ln(p)$ at the upper boundary with $\sigma_{11} = \sigma_{22} = \sigma$ is

$$\mu_p(\omega = \overline{\omega}) = \alpha^* - \alpha + \frac{\overline{\omega} - 1/r}{\overline{\omega} + 1/r}(1-\gamma)\sigma^2, \tag{6}$$

and at the lower boundary

$$\mu_p(\omega = \underline{\omega}) = \alpha^* - \alpha + \frac{\underline{\omega} - r}{\underline{\omega} + r}(1-\gamma)\sigma^2. \tag{7}$$

For realistic parameter values the mean reversion at the boundary gains in strength with shock diffusion, σ^2, and with risk aversion, $1-\gamma$.[17] The drift towards the center therefore shrinks as the economy is hit by smaller shocks. Therefore, because financial integration coincided with a period of "great moderation" (Kim & Nelson 1999, Stock & Watson 2002), it is not surprising that exchange rates do not appear more mean reverting today than in the past.

[Figure 1 about here.]

A key feature of our model is that drift and diffusion of the the real exchange rate vary systematically with its level. The upper panel of figure 1 shows the drift of two real exchange rate processes with different relocation costs. The process represented by the dashed line results from high relocation cost ($r = 0.78$), whereas the process represented by the solid line reflects low relocation cost ($r = 0.88$). Both processes share the property that a deviation from parity entails a drift of opposite sign. The diffusion, shown in the lower panel, decreases as real exchange rate deviations from parity become large. The real exchange rate process is therefore mean reverting at the boundaries of Ξ, but indistinguishable from a random walk close to parity. Clearly, increases in relocation cost not only widen the range of sustainable deviations from PPP, but also lower the drift at all real exchange rate levels. Likewise, they increase diffusion at all real exchange rate levels.

[Figure 2 about here.]

We now take a closer look at the high relocation cost scenario. Figure 2 compares the drift of the real exchange rate in a world, in which productivities are equal ($\alpha = \alpha^*$, dashed

[17] The necessary condition for this to hold is $\underline{\omega} < r$ and $\overline{\omega} > 1/r$. Table 1 shows that this is satisfied except for very small σ in combination with $\gamma \leq 0$.

line), with the drift in a world, in which productivities differ ($\alpha < \alpha^*$, solid line). The solid line shows that small differences in growth rates can shift the reversion target level away from PPP ($ln(p) = 0$) to a considerably different level ($ln(p) \approx -0.15$).[18] The tiny offset of the zero-drift point from the origin stems from the unequal country weights ($q \neq 1$).

Because this stylized model of arbitrage-induced trade[19] reflects only one segment of the economy, it leaves room for interpretation as to what precisely the good K is. The models only requirement is that K is the (only) factor of production, and that K is the (only) good consumed. We propose two interpretations – a final good interpretation and a productive capability interpretation. Under the final good interpretation K is a consumption good, such as "grain", which reproduces itself at rate α and can be consumed. Under the productive capability interpretation the good is "knowledge", which also reproduces itself, and is, via an (not modelled) production process, converted into a consumable, e.g. "movies".

2.2 Measuring Real Exchange Rates

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 final goods, and based on the CPI, WPI, or deflators of the gross domestic product (GDP). Each of these excludes a large share of productive capabilities, in particular immaterial goods. To compare the border effect of final goods with that of productive capabilities, we need one real exchange rate series for each.

For final goods we use the standard real exchange rate based on the WPI, which captures the bulkiness and business-to-business nature of these goods in international transactions.

Unfortunately, for productive capabilities no appropriate real exchange rate is readily available. Productive capabilities are factors in operation in the productive sector of the economy. They are typically owned by a firm, need to be combined with other capital goods in order to be fully useful,[20] and are often intangible (e.g. in the form of patents and

[18] If the productivity gap between two countries is extremely wide, then the drift can have the same sign at almost all real exchange rate levels. In this case the real exchange rate process is therefore divergent for half of its support, although it is still bounded by Ξ.

[19] As pointed out in appendix A this is not meant to be a model explaining standard trade flows.

[20] A major share of productive capabilities, except machinery, can be considered complementary factors. In the case of information technology investment, for example, only about one third of expenditures are invested in hardware and prepackaged software, whereas the rest is spent for complementary capital such as training, support, and custom software, which is a necessary requirement for the hardware to be useful within the productive sector (Basu, Fernald, Oulton & Srinivasan 2004, Kiley 1999). Caselli & Feyrer (2007) highlight 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

know-how). Clearly, none of the aforementioned real exchange rates focuses on productive capabilities, and for the most part they do not contain any productive capabilities at all. We therefore construct a novel real exchange rate series tailored to capture the valuation differences of productive capabilities between countries.

To demonstrate what data we need, we rewrite (5) by raising the fraction to higher terms using the world market price of an uninvested capital good, V_G.

$$p(\omega) = \frac{V_K(K, K^*)K/(V_G K)}{V_{K^*}(K, K^*)K^*/(V_G K^*)} \tag{8}$$

Notice that the market value of all productive capabilities, or invested capital goods, in a given country can be written as

$$M(t) = V_K\left(K(t), K^*(t)\right)K(t)e(t),$$

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

$$B(t) = V_G K(t)e(t)\varphi,$$

where φ denotes a time-invariant, country-specific accounting constant. The real exchange rate (8) can therefore be written in terms of (inflation-adjusted) market-to-book ratios, M/B, i.e.

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

Stock indices measure the total market *value* of productive capabilities of firms included in this stock index. The underlying *quantity* is captured by the aggregate book values, 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 via e.g. retained earnings or international relocation of productive capabilities, because the book values share the currency unit of the market value M, and obtain a measure of the value of one unit of

capital across countries does not differ by much, and thus border frictions for these goods are small. It is the other, complementary goods needed in the production process, such as human capital and technology, that explain the difference in the marginal product of capital. They point out that the scarcity of complementary capital goods, which are included in productive capabilities, and their higher cost explain investment into these countries. Our model predicts a similar link between high cost of productive capabilities and low new investment, but with causality running in the opposite direction. Without relocations, the less productive country is short of productive capabilities. Because relocation costs hinder a complete equalization of this imbalance, the price of productive capabilities in the less productive country is higher.

productive capability. For countries with identical accounting standards the real exchange rate of productive capabilities is thus simply the ratio of average 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 its interpretation in standard q-theory (Hayashi 1982). As the value of productive capabilities changes over time, the value of one unit of productive capability, measured by the market-to-book ratio, changes with it. Despite these fluctuations in market-to-book ratios, Tobin's q in our model is always unity, because the model does not explicitly consider the adjustment cost of investment within a given country.[21] In our setup the market-to-book ratio of a single country's stock index has therefore no economic meaning in isolation, but is informative *relative* to other countries' market-to-book ratio. The ratio of two countries' market-to-book ratios measures the relative price of productive capability in these two countries. In our model high relative market-to-book ratios between two countries lower future relative returns. This property of market-to-book ratios in our model is in line with the stylized fact that market-to-book ratios are inversely related to future equity returns (Fama & French 1992, Fama & French 1998, Pontiff & Schall 1998).

Our concept of the real exchange rate based on productive capabilities has multiple advantages. Firstly, it allows us to study properties of the market for productive capabilities in isolation from markets for other goods. In combination with our estimation approach, it enables us to estimate relocation costs of productive capabilities from macroeconomic data. With microeconomic data this has not been possible so far, because data on the cost of relocating productive capabilities across borders on a per-project basis is not publicly available.[22]

Secondly, because one component of market-to-book ratios is determined in financial markets, it responds quickly to new information. Accounting regulations (Nexia International 1993) restrict the revaluation of book values of productive capabilities. The rare revaluation 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,

[21] 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 productive capabilities (including goodwill) minus the book value of debt. Our model 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.

[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 productive capabilities.

book values a measure of the quantity of productive capabilities operating in an economy. Our approach mitigates problems with CPI and WPI data, which are subject to aggregation bias (Imbs, Mumtaz, Ravn & Rey 2005) and non-synchronous sampling (Taylor 2001). 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.

Our approach differs in important ways from the study of Engel & Rogers (1996) on the "width of the border", addressing many concerns pointed out by Gorodnichenko & Tesar (2009). For example, we do not rely on the unconditional variance of the real exchange rate as dependent variable. Our estimates are identified by time variation of country aggregates, not by within-country cross-section variation, and are therefore unaffected by differences in within-country price dispersion. Further, the real exchange rate for productive capabilities is – by virtue of the speed of financial markets – less persistent than a real exchange rate based on the CPI, and by its definition immune to pure nominal exchange rate changes.

2.3 Data

We collect data from various editions of Capital International Perspective (1975-2008). 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 December 2008.

[Figure 3 about here.]

The market-to-book ratios vary substantially over time. The solid line in figure 3 shows that the equal-weighted average market-to-book ratio trended upward over the last 30 years, with large transitory upward bursts, but returned close to unity during the 2008 financial crisis. 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 except in the recent 2005–2007 boom not all countries participated in these transitory upward bursts. After a few years variation returns back to the long-term base level. This foreshadows mean reversion of relative market-to-book values between countries, and thus of the real exchange rate for productive capabilities.

We correct book values for the effect of inflation, using WPI and CPI data provided by the International Monetary Fund's (IMF) International Financial Statistics database.[23] This correction adjusts, for example, the original bookvalues for Germany upwards during the high inflation periods of the 1970s.

We calculate the real exchange rate for final goods based on the monthly WPI from the IMF International Financial Statistics database for the same countries and time period. Subsequently, we demean the data and remove any seasonality effects by regression on a set of monthly dummies to account for cyclicality in economic activity or reporting.

[Figure 4 about here.]

Figure 4 compares our two measures of the real exchange rate.[24] The real exchange rate based on productive capabilities, represented by the solid line, moves less steadily than the real exchange rate for final goods, represented by the dashed line. Quite striking is the difference in evolution of the real exchange rate of productive capabilities during and after the communication technology boom. Canadian productive capabilities, shown in the top panel, reached their 30-year low in value relative to the USA shortly before the peak of the communication technology boom, reflecting the delayed growth of this sector in Canada. In contrast, German productive capabilities in the middle panel reached their all-time low in the after-technology-boom recession, which suggests that the 2002 recession had freed up more productive capabilities 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 final goods (Michael et al. 1997),[25] and we find a similar relationship for productive capabilities. We test the real exchange rate series of each of the 153 possible country pairs for ESTAR-type nonlinearity, using a Granger & Teräsvirta (1993)-type test. This test is based on a second-order Taylor approximation of the ESTAR function around $\theta = 0$.[26] As expected, real exchange rates

[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 $t-i$. Appendix C provides graphs of the effect of this book value correction.

[24] Appendix D presents graphs for additional country pairs.

[25] Broda & Weinstein (2008) find nonlinearity at the product level. At such a disaggregated level, however, nonlinearity may primarily be driven by strategic pricing: Temporary sale events by manufacturers or correlated sale events of distributors in limited marketing regions are very common. It is the very essence of a sale event that sale prices revert quickly back to their long-run levels. This type of mean reversion at the product level, however, does then not reflect international arbitrage or reversion back to an international PPP.

[26] Appendix E describes this test in more detail.

based on productive capabilities 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, figure 5 plots two-year changes in the log real exchange rate of productive capabilities against the initial log levels. Both country pairs shown feature random walk behavior close to the parity level and strong mean reversion away from parity. Visual inspection thus already indicates nonlinearity with two regimes.[27]

[Figure 5 about here.]

3 Indirect Inference

Our model has no closed form solution. Drift and diffusion are time-varying and functions of the unobserved imbalance, ω. In principle the coefficients on $I'(\omega)^{\frac{\gamma}{\gamma-1}}$, $(\gamma I(\omega) - \omega I'(\omega))^{\frac{\gamma}{\gamma-1}}$, $I(\omega)$, $\omega I'(\omega)$, and $\omega^2 I''(\omega)$ of differential equation (2) can be estimated by maximum likelihood (Brown & Hewitt 1975) after solving the nonlinear filtering problem of $\omega(t)$ based on the observations $p(t)$ (Bensoussan 1992). However, because the differential equation for p is not available in closed form, this calculation of ω_0 from $p(\omega_0)$ is computationally very costly and practically infeasible. Further, even after filtering and obtaining the series of ω, the closed form of the density of the conditional likelihood is not available because of the discreteness of the data. In contrast, going in the opposite direction, i.e. calculating $p(\omega_0)$ from ω_0 by (5), is a simple task, because the functional's value at ω_0, $I(\omega_0)$, is a by-product of calculating ω_0 via (2). More productive is therefore a method that does not require calculating the conditional distribution of $p(t)$ given $p(t-1)$ directly from the original model.

This estimation problem ideally suits the indirect inference procedure, introduced by Smith (1993), Gouriéroux, Monfort & Renault (1993) and Gallant & Tauchen (1996). Indirect inference replaces the hard-to-evaluate likelihood function of the original model with the likelihood function of an auxiliary model which is easier to estimate. Importantly, the auxiliary model must pick up the key features of interest of the data, in particular nonlinearity in drift and diffusion. One can then generate independent simulated data sets from the structural model for various parameters, 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

[27] Further, the 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.

on the actual data. Further, indirect inference does not require the hard 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, $p(\omega)$.

3.1 Auxiliary Model

The most crucial decision in indirect inference is choosing an appropriate auxiliary model. For the problem at hand, a natural auxiliary model is the ESTAR model of Haggan & Ozaki (1981) and Teräsvirta (1994). Whereas the process of the real exchange rate 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:

$$\begin{aligned} p_t - p_{t-1} &= (1-\Phi(\theta; p_{t-d}-\mu))\left(\beta_0 + (\beta_1 - 1)p_{t-1} + \sum_{j=1}^{m} \beta_j p_{t-j}\right) + \\ &+ (\Phi(\theta; p_{t-d}-\mu))\left(\beta_0^* + (\beta_1^* - 1)p_{t-1} + \sum_{j=1}^{m} \beta_j^* p_{t-j}\right) + \epsilon_t \qquad (9) \\ \epsilon_t &\sim N(0, \sigma_t^2) \end{aligned}$$

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_i and the outer autoregressive process with parameters β_i^*, and is specified as

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

We generalize the standard ESTAR to allow for conditional variance dynamics which our structural model (1) predicts. 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] In addition to time-varying conditional variance our specification restricts the outer

[28]Studies that allow for time-varying conditional variance in an ESTAR setup are scarce. A notable exception are Lundbergh & 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.

regime mean dynamics.

$$
\begin{aligned}
p_t - p_{t-1} &= (1-\Phi(\theta; p_{t-d}-\mu))\left((\beta_1 - 1)p_{t-1} + \sum_{j=1}^{m}\beta_j p_{t-j}\right) + \\
&- \Phi(\theta; p_{t-d}-\mu)p_{t-1} + \epsilon_t \\
\sigma_t^2 &= \left(1-\tilde{\Phi}(\tilde{\theta}; p_{t-d}-\mu)\right)\sigma_1^2 + \left(\tilde{\Phi}(\tilde{\theta}; p_{t-d}-\mu)\right)\sigma_2^2 \\
\tilde{\Phi}\left(\tilde{\theta}; p_{t-d}-\mu\right) &= 1 - exp\left(-\tilde{\theta}\left(p_{t-d}-\mu\right)^2\right) \\
\epsilon_t &\sim N(0, \sigma_t^2)
\end{aligned}
$$

We follow Teräsvirta (1994) in specifying the transition lag, d, and number of autoregressive terms, m, based on the nonlinearity test of Granger & Teräsvirta (1993), where we restrict $d \leq 12$ and $2 \leq m \leq 4$.

Michael et al. (1997) argue that real exchange rates based on CPI can be modeled by an ESTAR process. The same applies to real exchange rates based on productive capabilities. For most country pairs this real exchange rate follows a nonstationary inner regime and a stationary outer regime. Table 3 shows that the exchange rate processes for all country pairs have a stationary outer regime.[29]

[Table 3 about here.]

3.2 Discretization, Simulation and Optimization

Although the ESTAR estimates reveal nonlinearity in the data, they do not provide a natural interpretation of the autoregressive coefficients. Furthermore, they lack a natural benchmark for the transition parameter, θ. By estimating our structural model we can now ask whether θ is "big" or "small". In our indirect inference framework ESTAR assumes then the role of the auxiliary model.

Inspection of the estimation equations (2) with (3) and (4) reveals that in a country-by-country estimation not all parameters can be identified. Importantly, however, the real exchange rate process may be asymmetric, reflecting differences in productivity between countries. For example, the real exchange rate process may be close to one boundary most of the time, and hardly ever reach the other. To allow for this possibility we keep the

[29]Individual coefficients of the mean equation are often insignificant. Conversely, coefficient estimates of the variance equation are typically significant, often with a higher variance in the outer regime. If an outer variance regime cannot be identified, we impose a fixed variance regime $\sigma_t^2 = \sigma_1^2$ as in the standard ESTAR setup.

productivity differential $\Delta\alpha = \alpha - \alpha_{USA}$ as a parameter to be estimated. We calibrate $\alpha_{USA} = 0.180$ to the average growth rate of capital stock of the USA.[30] We assume equal variance $\sigma_{11} = \sigma_{22}$ and fix the discount rate at $\rho = 0.07$. A first stage estimation gives on average $\gamma \approx -0.5$. Because in our structural model γ applies to both the USA and each foreign country, we subsequently reestimate the model with γ fixed at this average to ensure the same U.S. risk aversion in each country pair.

Estimation requires the efficient simulation of many discrete trajectories of p for a given parameter set. We first simulate the $\tilde{\omega} = ln(\omega)$ process, which can be done with higher precision because the diffusion of this process is constant. Wagner & Platen (1978) and Platen (1981) introduce an Itô-Taylor scheme which strongly converges at rate 1.5.[31] Using the fact that the noise in our model is additive and the diffusion of $\tilde{\omega}$ is constant, this scheme can be written as

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

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.[32]

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.

In summary, we proceed with inference by the following steps:

1. Estimate the ESTAR specification based on actual data by quasi maximum likelihood. Denote the set of parameter estimates by $A_0 = \left\{\theta, \tilde{\theta}, \beta_i, \beta_i^*, \mu, \sigma_1, \sigma_2\right\}$.

2. Draw sequences of random numbers u_1 and u_2.

3. Pick starting values for the parameters of the structural model, $B = \{\gamma, r, \Delta\alpha, \sigma, q\}$.

4. Solve the differential equation for optimal boundaries, $\overline{\omega}$ and $\underline{\omega}$, using the Bulirsch–Stoer method, augmented by subsequent Newton optimization.

[30] We use annual 1974–2007 data from the World Development Indicators provided by the Worldbank to calculate α^* by

$$\alpha^* = \frac{GDP_T - GDP_0}{\sum_{t=0}^{T-1}(GDP_t - C_t)}.$$

[31] This convergence excels the rate of 1.0 achieved by the well-known Milstein (1974) scheme.

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

5. Simulate $S = 500$ paths of the imbalance process, ω_t, by the Itô-Taylor scheme for 649 periods based on the structural model. The first 240 periods, or 20 years, are used as burn-in period. They are discarded to ensure that the results are independent from the starting values of the process. This leaves us with $T = 409$ simulated values.

6. Calculate the price process, $p(\omega_t)$, from the imbalance process.

7. Compute the indirect inference estimate of B by minimizing the distance between the data-based and the simulation-based estimate, measured by the score criterion

$$\begin{aligned}\hat{B} &= \operatorname*{argmin}_{B} \left[\sum_{s=1}^{S} \sum_{t=1}^{T} \frac{\partial \ln f^{ESTAR}}{\partial A} \left(p_t^s(B) | p_{t-1}^s, A_0 \right) \right]' \\ &\times \ \Omega \times \left[\sum_{s=1}^{S} \sum_{t=1}^{T} \frac{\partial \ln f^{ESTAR}}{\partial A} \left(p_t^s(B) | p_{t-1}^s, A_0 \right) \right],\end{aligned}$$

where Ω is a nonnegative, symmetric weighting matrix.

4 Empirical Results

We apply our estimation procedure to the real exchange rates of both final goods and productive capabilities with the USA as base country. The estimated relocation cost for final goods given in the first column of table 4 ranges from 2% for Canada–USA up to 26% for France–USA, with a median of about 13%. The picture changes dramatically when we shift our focus to productive capabilities. The second column of this table reports for all countries except Austria, France, and UK much larger relocation costs of productive capabilities than of final goods, with a median of about 18%. The variation of these costs across countries is considerably higher as well, ranging from 11% to 54%. But there are also similarities: On the one hand, the direct neighbor of the USA, Canada, has the lowest relocation cost to and from the USA for both classes of goods, 2% for final goods and 11% for productive capabilities. On the other hand, the distant large economy Japan has a high relocation cost for both classes of goods, 22% for final goods and 28% for productive capabilities.

Our parameter estimates allow us to graphically compare the drift and diffusion processes. As an example, we discuss here the real exchange rates of the pair Germany–USA. Figure 6 emphasizes the very different border costs for final goods and productive capabilities. The real exchange rate process for final goods, shown by the dashed line, follows a much narrower band with lower diffusion than the process for productive capabilities. The mean reversion properties of final goods resemble those of productive capabilities, but cut off at much tighter boundaries, which limits the maximum mean reversion of the real exchange rate of final goods.

[Figure 6 about here.]

Figures 7 and 8 compare the real exchange rate process for productive capabilities of Germany–USA, shown as dashed line, with other country pairs.

[Figure 7 about here.]

The process for Japan–USA in figure 7 moves with a smaller variance within a much wider band. Its mean reversion is extremely small.

[Figure 8 about here.]

In contrast, the solid line in figure 8 displays a country pair with mean reversion as strong as, but much more rapid, than Germany–USA. The shown country pair with a narrow real exchange rate band is UK–USA, which is among the country pairs with the lowest relocation costs for productive capabilities. Both its mean reversion and maximum diffusion are higher than in Germany–USA. The upper panel of this figure also shows that the drift of the real exchange rates at parity is negative, which is an effect of the higher productivity of the UK relative to the USA and the, as a result, relative abundance of goods in the UK. Because the USA itself reproduces goods a lower rate, only a large abundance of goods in the UK, i.e. a small p, triggers a relocation of goods from the UK to the USA.

The third column of table 4 compares the relocation cost of final goods with the corresponding cost of productive capabilities directly. Relocation cost for productive capabilities are about 50% higher than for final goods. The close economic ties between the UK and the USA are reflected in a low relocation cost of productive capabilities, even lower than the cost of moving final goods. Norway, Sweden, and Canada display a very pronounced cost pattern. Whereas its trade costs are relatively low, its relocation costs for productive capabilities are much larger, pointing to differences in openness between markets.

[Table 4 about here.]

Figure 9 emphasizes the higher relocation cost for productive capabilities than for final goods. Overall, the relocation costs are only weakly correlated between the two types of goods. Besides Canada, the countries UK, Denmark, Germany, Italy, and the Netherlands have low costs for both types of goods. Hongkong, Norway, and Sweden appear to be somewhat disconnected from the market for productive capabilities.

[Figure 9 about here.]

[Table 5 about here.]

In the left half of table 5 we rank all countries in our sample by their cost of transferring final goods to and from the USA. By far the lowest border cost obtains between the USA and Canada. Only 2% of the quantity of final goods crossing this border is lost in the form of iceberg costs. On the other extreme, a transfer of final goods from Japan to the USA incurs a cost of more than 20%. Besides the distant economy Japan, relatively small or protected markets such as Switzerland, Belgium, Austria, or France are among the countries with the highest trade cost to and from the USA.

We compare our estimates with the ratio of cost-insurance-freight (*cif*) and free-on-board (*fob*) prices provided by the IMF's International Financial Statistics database for a few countries. For countries in our sample both *cif* and *fob* values of imports are available for Australia, France, Germany, UK, and USA. The average *civ*/*fob* ratio for these countries fell from approximately 6% in 1975 to approximately 4.5% today. All transfer cost estimates except for Canada and Sweden exceed this level. This emphasizes that transfer cost consists of more than just insurance and freight. Other expenses, such as e.g. administration, customs, distribution, and market access costs devour up to another 20% of the transferred quantity in the case of France and Japan.[33]

The right half of table 5 ranks the same countries again, but now by their cost of relocating productive capabilities to and from the USA. This heavily reshuffles the ordering of countries. Hongkong, Norway, and Sweden are economies which are quite open for trade in final goods, but largely closed for transfers of productive capabilities. Borders to Austria and the UK, on the contrary, seem to impose less frictions on productive capabilities than on final goods. The logic behind the ordering seems to very different between the two types of goods. For productive capabilities, European open economies impose the lowest frictions, whereas Asian economies and economies with more government activity tend to show higher frictions. For final goods, however, these factors do not matter. In contrast, small economies and economies with specific market structures appear to impose the higher frictions on final goods markets.

[33] These border cost estimates are somewhat smaller than the average estimate in the literature. The transfer cost equivalent of the estimate in the survey of Anderson & van Wincoop (2004) is more than 20% for a representative rich country.

In order to put our estimates for productive capabilities into perspective, we compare them with estimates of adjustment costs. The adjustment cost of capital goods within a country, i.e. the difference between the productive capability's value as part of a firm and the proceeds from selling the dismantled capital good, provide an upper bound on how large relocation costs of productive capabilities within a country can be. In a setup similar to Abel & Eberly (1994) and Abel & Eberly (1996), where the only form of adjustment cost is a gap between buying and selling prices of capital goods, Cooper & Haltiwanger (2006) find for the USA an adjustment loss of about 20%. Many of these intra-US adjustment losses are larger than our estimates for relocation costs. For most country pairs in our sample a direct relocation of productive capabilities is therefore cheaper than a disinvestment and subsequent transfer as final good, whereas for Hongkong, Norway, and Sweden the border imposes considerable additional friction for productive capabilities.

The relocation cost parameter, r, our key parameter of interest, is estimated with small standard error. r captures most of the nonlinearity of the process, which is the key feature of the auxiliary model, and the motivation for our estimation strategy. The relocation discounts differ significantly from zero and unity for all country pairs. That is, for both real exchange rates we reject both of the extremes random walk ($r = 0$) and constant ($r = 1$). All other parameters are estimated with much larger standard errors, and help primarily in fitting the model. The average estimates, however, are of some interest on their own:[34] The median estimated productivity differential relative to the USA, $\Delta\alpha$, is +0.02 for final goods, but less than zero for productive capabilities. This might indicate that relative to the other countries in the sample the USA is better at producing productive capabilities, e.g. ideas, than at producing final goods. Likewise, the median welfare weight, q, on the foreign country for final goods is above one, whereas it is only 0.9 for productive capabilities. Interpreting these weights as a reflection of initial endowments, this indicates that the USA started with higher endowments of productive capabilities than its peers. Finally, the mean volatility estimate, σ, for final goods of 0.46 is considerably smaller than the estimate for productive capabilities of 0.55. Clearly, the creation process of productive capabilities (Schumpeter (1942)'s "creative destruction") involves more risk.

Until now we have derived a new way of measuring the cost of relocating productive capabilities from one country to another, and found this cost to be larger than the corresponding cost for final goods. But what are the underlying causes for these costs? To answer this question, we regress the natural logarithm of our border cost measures on four explanatory

[34] Appendix F provides detailed results for all 17 country pairs.

factors commonly used in international trade. The independent variables are distance, the absolute 2003 GDP difference, and a dummy for common language.

[Table 6 about here.]

[Table 7 about here.]

Table 6 reveals that geographic distance affects the relocation cost for final goods, but not for productive capabilities. For every 1000 kilometers of geographic distance, the relocation cost for final goods increases by more than one percent of the transferred quantity. But as McCallum (1995) and Engel & Rogers (1996) have pointed out, there is more to a border than just geographic distance, and this is what matters for productive capabilities. This is captured by the relocation cost for productive capabilities: The left column of table 7 reveals that the cost reflected in prices of productive capabilities have additional explanatory power of the merger and acquisition (M&A) activity with the U.S., even after controlling for distance, language, and GDP. The relocation cost of final goods, however, does not explain M&A activity, simply because M&A does not involve the relocation of physical goods, but often a transfer of knowledge.

Having established mean reversion as a property of the real exchange rate, we want to know how long full mean reversion to the parity level takes. We therefore calculate the time that it takes the real exchange rate process on average to hit a boundary when started at a balanced level, and the time it takes to revert to this level if started at either boundary. Despite mean reversion, these so-called hittimes are for many countries two years and more. An extreme case is Japan-USA in table 9; these hittimes are, in the words of Rogoff (1996), "glacial". However, there are notable exceptions. Table 8 lists the hittimes for the example Germany–USA, which are obtained by integrating over the appropriately scaled speed density (Karlin & Taylor 1981). The real exchange rate of final goods takes about 1.5 years from the upper boundary to a balanced level and vice versa. Despite the higher relocation cost this time interval for productive capabilities is only about 2/3 that long. This stems from the higher variance for productive capabilities, which illustrates that a narrow range of the real exchange rate is *not* equivalent to fast mean reversion. In fact, a narrow range for p does not necessarily imply a narrow range for ω. The deterministic drift weakens as the real exchange rate approaches the balanced level, and it requires a random shock to push the exchange rate through its zero-drift level. Likewise, only large random shocks push the exchange rate to the boundary despite a mean reverting drift.

[Table 8 about here.]

[Table 9 about here.]

Furthermore, if country pairs are asymmetric, then the mean reversion time depends on which boundary the process starts. In our example Germany–USA, returning to a balanced level from a situation where the USA enjoys maximum abundance takes about as long as returning from the opposite boundary. For Japan-USA, in contrast, the mean reversion times differ considerably depending on the boundary. The reason is the productivity differential, which makes e.g. keeping an excess amount of final goods in Japan attractive, and which makes the stock of final goods in the Japan grow faster than in the USA.

The hittime distribution is very skewed. Figure 10 shows that a large number of shocks to PPP which decay quickly within, say, a year, is offset by a smaller number of extremely slowly decaying deviations, with hittimes of five years and more. Hittimes also vary considerably between countries. Taken together this may explain the inconclusiveness of the data about halftimes of mean reversion documented by Kilian & Zha (2002).

[Figure 10 about here.]

In summary, relocation of productive capabilities across a border is more costly than relocation of final goods. Borders affect productive capabilities more than final goods. In particular, geographic distance increases the relocation cost for productive capabilities, but relative economic size seems to matter as well. In effect, returning from a maximum imbalance to a balanced position takes several years and this long time span obtains despite the real exchange rate process clearly does not follow a random walk.

5 Conclusion

Our alternative real exchange rate measure, based on accounting data, and nonlinearities in the real exchange rate process carry useful additional foreign exchange market information. Based on a novel approach to estimating border cost directly from the real exchange rate series we find borders to increase the relocation cost of productive capabilities considerably more than of final goods. This indicates that markets for productive capabilities and final goods are at different stages of integration.

Our approach confirms that the real exchange rate follows an overall stationary, nonlinear process, which is indistinguishable from a random walk close to parity, and provides an important new insight: As further integration of the world economy continues to shrink the barriers to trade, the range of values assumed by the real exchange rate will shrink as well. But if volatility shrinks at the same time, mean reversion might in fact *not* accelerate, despite shrinking barriers. Thus no matter how easy it eventually will become to relocate goods, the random walk behavior in the inner regime will ensure that reversion to PPP will remain slow.

Three important implications for the forecasting of real exchange rates can be taken from this study. First, there is long-run predictability in line with Kilian & Taylor (2003) despite short-run random walk behavior. Second, our work emphasizes that for a meaningful forecast the *definition* of the real exchange rate must be tailored to the market of interest. Third, and importantly, border cost, endowment shocks, and its determining factors affect the drift and can therefore help in forecasting real exchange rates.

References

Abel, Andrew B. & Janice C. Eberly (1994), ‘A unified model of investment under uncertainty’, *American Economic Review* **84**(5), 1369–1384.

Abel, Andrew B. & Janice C. Eberly (1996), ‘Optimal investment with costly reversibility’, *Review of Economic Studies* **63**(4), 581–593.

Adler, Michael & Bruce Lehman (1983), ‘Deviations from purchasing power parity in the long run’, *Journal of Finance* **38**(5), 1471–1487.

Allen, Franklin & Douglas Gale (1994), *Financial Innovation and Risk-Sharing*, MIT Press, Cambridge.

Anderson, James A. & Eric van Wincoop (2003), ‘Gravity with gravitas: A solution to the border puzzle’, *American Economic Review* **93**(1), 170–192.

Anderson, James A. & Eric van Wincoop (2004), ‘Trade costs’, *Journal of Economic Literature* **42**(3), 691–751.

Backus, David K., Patrick J. Kehoe & Finn E. Kydland (1992), ‘International real business cycles’, *Journal of Political Economy* **100**(4), 745–775.

Baker, Malcolm, C. Fritz Foley & Jeffrey Wurgler (2009), ‘Multinationals as arbitrageurs: The effect of stock market valuations on foreign direct investment’, *Review of Financial Studies* **22**(1), 337–369.

Balke, Nathan S. & Thomas B. Fomby (1997), ‘Threshold cointegration’, *International Economic Review* **38**(3), 627–645.

Balvers, Ronald, Yangru Wu & Erik Gilliland (2000), ‘Mean reversion across national stock markets and parametric contrarian investment strategies’, *Journal of Finance* **55**(2), 745–772.

Basak, Suleyman & Benjamin Croitoru (2007), ‘International good market segmentation and financial innovation’, *Journal of International Economics* **71**(2), 267–293.

Basu, Susanto, John G. Fernald, Nicholas Oulton & Sylaja Srinivasan (2004), The case of missing productivity growth: or, does information technology explain why productivity accelerated in the United States but not in the United Kingdom?, *in* M.Gertler & K.Rogoff, eds, ‘NBER Macroeconomics Annual 2003’, Vol. 18, pp. 9–82.

Bensoussan, Alain (1992), *Stochastic Control of Partially Observable Systems*, Cambridge University Press, Cambridge.

Broda, Christian & David E. Weinstein (2008), ‘Understanding international price differences using barcode data’, *NBER Working Paper* **14017**.

Brown, B. M. & J. I. Hewitt (1975), ‘Asymptotic likelihood theory for diffusion processes’, *Journal of Applied Probability* **12**(2), 228–238.

Capital International Perspective (1975-2008), Morgan Stanley Capital International Perspective, Technical report, Morgan Stanley Capital International, Geneva. Monthly issues, January 1975 - December 2008.

Caselli, Francesco & James Feyrer (2007), ‘The marginal product of capital’, *Quarterly Journal of Economics* **122**(2), 535–568.

Cooper, Russel W. & John C. Haltiwanger (2006), ‘On the nature of capital adjustment costs’, *Review of Economic Studies* **73**(3), 611–633.

Dumas, Bernard (1992), ‘Dynamic equilibrium and the real exchange rate in a spatially separated world’, *Review of Financial Studies* **5**(2), 153–180.

Dumas, Bernard & Raman Uppal (2001), ‘Global diversification, growth and welfare with imperfectly integrated markets for goods’, *Review of Financial Studies* **14**(1), 277–305.

Eaton, Jonathan & Samuel Kortum (1999), ‘International technology diffusion: Theory and measurement’, *International Economic Review* **40**(3), 537–570.

Engel, Charles & John H. Rogers (1996), ‘How wide is the border?’, *American Economic Review* **86**(5), 1112–1125.

Fama, Eugene F. & Kenneth R. French (1992), ‘The cross-section of expected stock returns’, *Journal of Finance* **47**(2), 427–465.

Fama, Eugene F. & Kenneth R. French (1998), ‘Value versus growth: The international evidence’, *Journal of Finance* **53**(6), 1975–1999.

Frankel, Jeffrey A. & Andrew K. Rose (1996), ‘A panel project on purchasing power parity: Mean reversion within and between countries’, *Journal of International Economics* **40**(1–2), 209–224.

Franses, Philip & Dick van Dijk (2000), *Nonlinear Time Series Models in Empirical Finance*, Cambridge University Press, Cambridge.

Froot, Kenneth A. & J. Stein (1991), 'Exchange rates and foreign direct investment: An imperfect capital markets approach', *Quarterly Journal of Economics* **106**(4), 1191–1217.

Froot, Kenneth A. & Kenneth S. Rogoff (1995), Perspectives on PPP and long-run exchange rates, *in* G. Grossman & K. S. Rogoff, eds, 'Handbook of International Economics', Vol. 3, North Holland, Amsterdam, pp. 1647–1688.

Gallant, A. Ronald & George E. Tauchen (1996), 'Which moments to match?', *Econometric Theory* **12**(4), 657–681.

Gorodnichenko, Yuriy & Linda L. Tesar (2009), 'Border effect or country effect? Seattle may not be so far from Vancouver after all', *American Economic Journal: Macroeconomics* **1**(1), 219–241.

Gouriéroux, Christian, Alain Monfort & Eric Renault (1993), 'Indirect inference', *Journal of Applied Econometrics* **8**, S85–S118.

Granger, Clive W.J. & Timo Teräsvirta (1993), *Modelling Nonlinear Economic Relationships*, Oxford University Press, Oxford.

Haggan, Valérie & Tohru Ozaki (1981), 'Modeling nonlinear random vibrations using an amplitude-dependent autoregressive time-series model', *Biometrica* **68**(1), 189–196.

Hayashi, Fumio (1982), 'Tobin's marginal q and average q: a neoclassical interpretation', *Econometrica* **50**(1), 213–224.

Heckscher, Eli F. (1916), 'Vaxelkursens grundval vid pappersmyntfot', *Ekonomisk Tidskrift* **18**(10), 309–312.

Hsieh, Chang-Tai & Peter J. Klenow (2007), 'Relative prices and relative prosperity', *American Economic Review* **97**(3), 562–585.

Imbs, Jean, Haaron Mumtaz, Morten O. Ravn & Helene Rey (2003), 'Non-linearities and real exchange rate dynamics', *Journal of the European Economic Association* **2–3**(1), 639–649.

Imbs, Jean, Haaron Mumtaz, Morten O. Ravn & Helene Rey (2005), ‘PPP strikes back: Aggregation and the real exchange rate’, *Quarterly Journal of Economics* **120**(1), 1–43.

Karlin, Samuel & Howard M. Taylor (1981), *A Second Course in Stochastic Processes*, Academic Press, San Diego.

Kiley, Michael T. (1999), Computers and growth with costs of adjustment: will the future look like the past?, Finance and Economics Discussion Paper 36, Board of Governors of the Federal Reserve System.

Kilian, Lutz & Mark P. Taylor (2003), ‘Why is it so difficult to beat the random walk forecast of exchange rates?’, *Journal of International Economics* **60**(1), 85–107.

Kilian, Lutz & Tao Zha (2002), ‘Quantifying the uncertainty about the half-life of deviations from PPP’, *Journal of Applied Econometrics* **17**(2), 107–125.

Kim, Chang-Jin & Charles R. Nelson (1999), ‘Has the u.s. economy become more stable? a bayesian approach based on a markov-switching model of the business cycle.’, *Review of Economics and Statistics* **81**(4), 608–616.

Kloeden, Peter E. & Eckhard Platen (1999), *Numerical Solutions to Stochastic Differential Equations*, Springer, Berlin.

Lothian, James R. & Mark P. Taylor (1996), ‘Real exchange rate behavior: The recent float from the perspective of the past two centuries’, *Journal of Political Economy* **104**(3), 488–509.

Lucas, Robert E. (1990), ‘Why doesn’t capital flow from rich to poor countries?’, *American Economic Review* **80**(2), 92–96.

Lundbergh, Stefan & Timo Teräsvirta (2006), ‘A time series model for an exchange rate in a target zone with applications’, *Journal of Econometrics* **131**(1–2), 579–609.

McCallum, John (1995), ‘National borders matter: Canada–US regional trade patterns’, *American Economic Review* **85**(3), 615–623.

Michael, Panos, Robert Nobay & David Peel (1997), ‘Transactions costs and nonlinear adjustment in real exchange rates: An empirical investigation’, *Journal of Political Economy* **105**(4), 862–879.

Milstein, Grigoriĭ N. (1974), 'Approximate integration of stochastic differential equations', *Theory of Probability and Applications* **19**, 557–562.

Murray, Christian J. & David H. Papell (2005), 'The purchasing power parity puzzle is worse than you think', *Empirical Economics* **30**(3), 783–790.

Nexia International (1993), *The International Handbook of Financial Reporting*, Chapman and Hall, New York.

Obstfeld, Maurice & Alan M. Taylor (1997), 'Nonlinear aspects of goods-market arbitrage and adjustment: Heckschers commodity points revisited', *Journal of the Japanese and International Economies* **11**(4), 441–479.

Obstfeld, Maurice & Kenneth S. Rogoff (2001), The six major puzzles in international macroeconomics: Is there a common cause?, *in* B. S. Bernanke & K. S. Rogoff, eds, 'NBER Macroeconomics Annual 2000', MIT Press, Cambridge, pp. 339–389.

O'Connel, Paul G.J. & Shang-Jin Wei (2002), "The bigger they are, the harder they fall': Retail price differences across U.S. cities', *Journal of International Economics* **56**(1), 21–53.

Platen, Eckhard (1981), 'An approximation method for a class of Itô processes', *Lietuvos Matematikos Rinkinys* **21**(1), 121–133.

Polk, Christopher & Paola Sapienza (2009), 'The stock market and corporate investment: a test of catering theory', *Review of Financial Studies* **22**(1), 187–217.

Pontiff, Jeffrey & Lawrence D. Schall (1998), 'Book-to-market ratios as predictors of market returns', *Journal of Financial Economics* **49**(2), 141–160.

Prakash, Gauri & Alan M. Taylor (1997), 'Measuring market integration: a model of arbitrage with an econometric application to the gold standard, 1879-1913', *NBER Working Paper* **6073**.

Press, William H., Saul A. Teukolsky, William T. Vetterling & Brian P. Flannery (2001), *Numerical Recipes in Fortran 77, The Art of Scientific Computing*, 2nd edn, Cambridge University Press, Cambridge.

Ravn, Morten O. & Elisabetta Mazzenga (2004), 'International business cycles: the quantitative role of transportation costs', *Journal of International Money and Finance* **23**(4), 645–671.

Richards, Anthony (1995), 'Comovements in national stock market returns: Evidence of predictability, but not cointegration', *Journal of Monetary Economics* **36**(3), 631–654.

Rogoff, Kenneth S. (1996), 'The purchasing power parity puzzle', *Journal of Economic Literature* **34**(2), 647–668.

Rogoff, Kenneth S., Kenneth A. Froot & Michael Kim (2001), The law of one price over 700 years, Working Paper 01/174, International Monetary Fund.

Sarno, Lucio (2005), 'Viewpoint: Towards a solution to the puzzles in exchange rate economics: where do we stand?', *Canadian Journal of Economics* **38**(3), 673–708.

Schumpeter, Joseph A. (1942), *Capitalism, socialism and democracy*, Harper, New York/London.

Sercu, Piet, Raman Uppal & Cynthia van Hulle (1995), 'The exchange rate in the presence of transaction costs: Implications for tests of purchasing power parity', *Journal of Finance* **50**(4), 1309–1319.

Smith, Anthony A. (1993), 'Estimating nonlinear time-series models using simulated vector autoregressions', *Journal of Applied Econometrics* **8**, S63–S84.

Stock, James H. & Mark W. Watson (2002), Has the business cycle changed and why?, *in* M.Gertler & K.Rogoff, eds, 'NBER Macroeconomics Annual 2002', Vol. 17, MIT Press, Cambridge, pp. 159–230.

Stoer, Josef & Roland Bulirsch (2005), *Numerische Mathematik 2*, 5^{th} edn, Springer, Berlin.

Taylor, Alan M. (2001), 'Potential pitfalls for the purchasing-power-parity puzzle? Sampling and specification biases in mean-reversion tests of the law of one price', *Econometrica* **69**(2), 473–498.

Taylor, Mark P. (2005), Real exchange rates and nonlinearities, *in* P. D. Grauwe, ed., 'Exchange Rate Economics', CESifo Seminar Series, MIT Press, London, pp. 87–123.

Taylor, Mark P., David A. Peel & Lucio Sarno (2001), 'Nonlinear mean reversion in real exchange rates: Toward a solution to the purchasing power parity puzzles', *International Economic Review* **42**(4), 1015–1042.

Teräsvirta, Timo (1994), 'Specification, estimation and evaluation of smooth transition autoregressive models', *Journal of the American Statistical Association* **89**(425), 208–218.

Tong, Howell (1990), *Nonlinear Time Series: A Dynamical System Approach*, Oxford University Press, Oxford.

Uppal, Raman (1993), 'An general equilibrium model of international portfolio choice', *Journal of Finance* **48**(2), 529–553.

Wagner, Wolfgang & Eckhard Platen (1978), Approximation of Itô integral equations, Preprint, Zentralinstitut für Mathematik and Mechanik, Akademie der Wissenschaften, Berlin.

Table 1: Maximum Sustainable Imbalance ($\overline{\omega}$)

(a) for Small Relocation Cost

Risk av.	Risk ($\sigma_{11} = \sigma_{22}$)					
$(1-\gamma)$	0^+	0.02	0.1	0.5	1	∞
0	∞	∞	∞	∞	∞	∞
0.5	1.23	1.64	2.63	3.25	3.29	3.30
1	1.11	1.41	2.11	2.56	2.59	2.59
1.5	1.07	1.34	1.94	2.29	n.a.	n.a.
2	1.05	1.31	1.86	2.13	n.a.	n.a.
3	1.04	1.28	1.75	n.a.	n.a.	n.a.

Parameter values $r = 0.9$, $\rho = 0.07$, $\alpha = \alpha^* = 0.1$, $q = 1$

(b) for High Relocation Cost

Risk av.	Risk ($\sigma_{11} = \sigma_{22}$)					
$(1-\gamma)$	0^+	0.02	0.1	0.5	1	∞
0	∞	∞	∞	∞	∞	∞
0.5	1.78	2.32	3.95	5.88	6.06	6.13
1	1.33	1.69	2.76	4.12	4.26	4.31
1.5	1.21	1.54	2.46	3.53	n.a.	n.a.
2	1.15	1.47	2.31	3.21	n.a.	n.a.
3	1.10	1.41	2.15	n.a.	n.a.	n.a.

Parameter values $r = 0.75$, $\rho = 0.07$, $\alpha = \alpha^* = 0.1$, $q = 1$

Table 2: Expected Time until First Transfer

(a) for Small Relocation Cost

risk av. $1-\gamma$	risk σ 0^+	0.02	0.1	0.5	1	∞
0	∞	∞	∞	∞	∞	∞
0.5	∞	123.99	31.03	2.62	0.68	0
1	∞	51.47	17.62	1.70	0.45	0
1.5	∞	37.13	14.33	1.35	n.a.	n.a.
2	∞	31.22	12.70	1.15	n.a.	n.a.
3	∞	26.01	10.94	n.a.	n.a.	n.a.

Parameter values $r = 0.9$, $\rho = 0.07$, $\alpha = \alpha^* = 0.1$, $q = 1$, starting at balanced level $\omega_0 = 0$

(b) for High Relocation Cost

risk av. $1-\gamma$	risk σ 0^+	0.02	0.1	0.5	1	∞
0	∞	∞	∞	∞	∞	∞
0.5	∞	529.07	57.88	5.61	1.50	0
1	∞	147.31	28.55	3.73	1.03	0
1.5	∞	84.09	22.18	3.06	n.a.	n.a.
2	∞	61.04	19.39	2.70	n.a.	n.a.
3	∞	43.30	16.78	n.a.	n.a.	n.a.

Parameter values $r = 0.75$, $\rho = 0.07$, $\alpha = \alpha^* = 0.1$, $q = 1$, starting at balanced level $\omega_0 = 0$

Table 3: Stationarity of ESTAR Regimes

	inner regime (AR)		outer regime (AR $\times\Phi$)	
	avg. root	non-stationary	avg. root	non-stationary
final goods	1.009	29%	1.068	0
productive capabilities	0.999	53%	1.080	0

Table 4: Relocation Cost, Comparison of Final Goods with Productive Capabilities

	r_{WPI}	r_{CAP}	$\frac{1-r_{CAP}}{1-r_{WPI}}$
Australia	0.84	0.79	1.3
Austria	0.79	0.84	0.8
Belgium	0.82	0.82	1.0
Canada	0.98	0.89	5.2
Denmark	0.88	0.83	1.5
France	0.74	0.75	1.0
Germany	0.89	0.85	1.3
Hongkong	0.91	0.46	6.0
Italy	0.89	0.84	1.5
Japan	0.78	0.72	1.3
Netherlands	0.89	0.82	1.7
Norway	0.93	0.47	7.9
Singapore	0.86	0.73	2.0
Spain	0.86	0.49	3.6
Sweden	0.98	0.64	20.2
Switzerland	0.84	0.84	1.0
UK	0.87	0.89	0.8

Inflation-adjusted bookvalues, demeaned and deseasonalized, 1974:12–2008:12.
ESTAR as auxiliary model with $2 \leq p \leq 4$ and $d \leq 12$ chosen by nonlinearity test.

Table 5: Relocation Cost vs. USA

Final Goods: r_{WPI}		Productive Capabilities: r_{CAP}	
Canada	0.98 (0.00)	**Canada**	0.89 (0.02)
Sweden	0.98 (0.00)	**UK**	0.89 (0.00)
Norway	0.93 (0.01)	**Germany**	0.85 (0.02)
Hongkong	0.91 (0.01)	Austria	0.84 (0.05)
Germany	0.89 (0.02)	Switzerland	0.84 (0.01)
Netherlands	0.89 (0.01)	Italy	0.84 (0.03)
Italy	0.89 (0.07)	Denmark	0.83 (0.07)
Denmark	0.88 (0.02)	Netherlands	0.82 (0.00)
UK	0.87 (0.01)	Belgium	0.82 (0.09)
Singapore	0.86 (0.01)	Australia	0.79 (0.02)
Spain	0.86 (0.02)	France	0.75 (0.01)
Australia	0.84 (0.02)	Singapore	0.73 (0.04)
Switzerland	0.84 (0.02)	**Japan**	0.72 (0.01)
Belgium	0.82 (0.02)	Sweden	0.64 (0.06)
Austria	0.79 (0.01)	Spain	0.49 (0.73)
Japan	0.78 (0.02)	Norway	0.47 (0.02)
France	0.74 (0.06)	Hongkong	0.46 (0.11)

Inflation-adjusted bookvalues, demeaned and deseasonalized, 1974:12–2008:12.
ESTAR as auxiliary model with $2 \leq p \leq 4$ and $d \leq 12$ chosen by nonlinearity test.
Standard errors in parentheses.

Table 6: Trade Components of Relocation Cost

	productive capabilities $log(r_{CAP})$	final goods $log(r_{WPI})$
Distance	-0.17	-0.11*
	(0.21)	(0.06)
Common language	0.06	0.06
	(0.14)	(0.04)
Δ GDP	-0.05	0.03
	(0.06)	(0.02)
Constant	0.32	-0.35
	(0.63)	(0.18)
Adj. R^2	-0.11	0.20

Dependent variable: $ln(r)$, independent variables: distance (in 10000 km), common language (1 if common language, 0 otherwise), absolute GDP difference (trillion USD at PPP, 2003). Sample size $N = 17$. Standard errors in parentheses. (* significant at the 10% level)

Table 7: Relocation Cost as Determinant of Crossborder Mergers

	Mergers $log(r_{CAP})$	Mergers $log(r_{WPI})$
Relocation cost	753**	-1137
	(325)	(1341)
Distance	-2066***	-2318***
	(267)	(317)
Common language	1622***	1732***
	(161)	(202)
Total GDP	358***	364***
	(74)	(93)
Constant	-2003***	-2287
	(940)	(1116)
Adj. R^2	0.91	0.88

Dependent variable: total mergers with a US firm on one side, independent variables: $ln(r)$, distance (in 10000 km), common language (1 if common language, 0 otherwise), total GDP (trillion USD at PPP, 2003). Sample size $N = 17$. Standard errors in parentheses. (* significant at the 10% level, ** at 5% level, *** at 1% level)

Table 8: Hittimes in years, Example Germany–USA

first hit of	starting at	final goods	productive capabilities
any boundary	ω_0	1.3	1.0
upper boundary $\overline{\omega}$	ω_0	4.2	3.0
lower boundary $\underline{\omega}$	ω_0	4.2	3.0
balanced level ω_0	$\overline{\omega}$	1.4	0.9
balanced level ω_0	$\underline{\omega}$	1.4	1.1

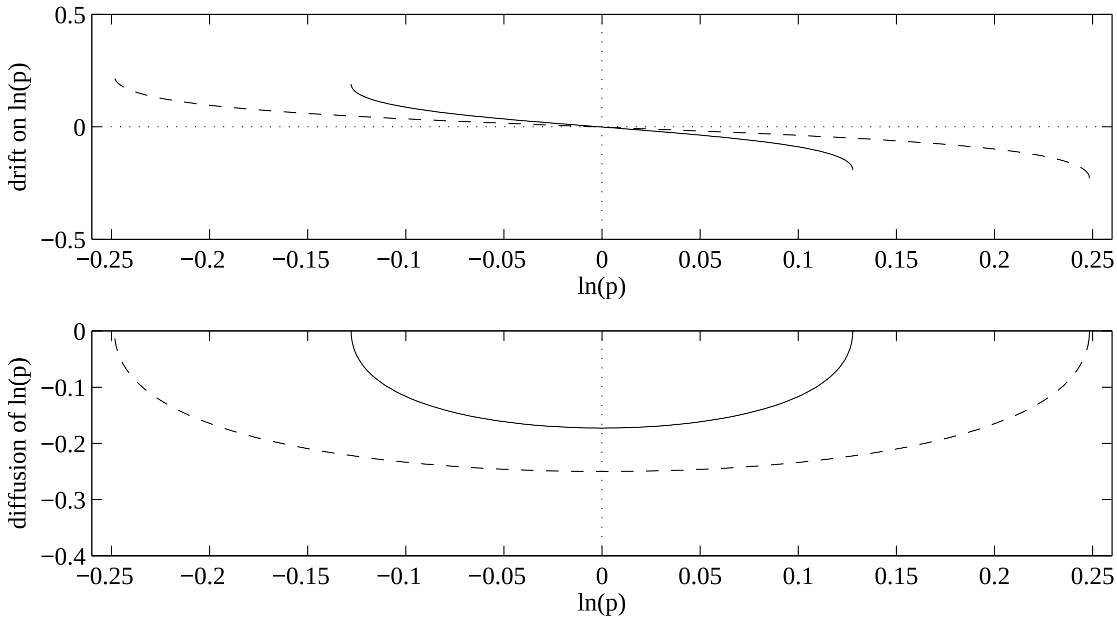
balanced level $\omega_0 = 0$

Table 9: Hittimes in years, Example Japan–USA

first hit of	starting at	final goods	productive capabilities
any boundary	ω_0	3.8	10.6
upper boundary $\overline{\omega}$	ω_0	11.7	126.8
lower boundary $\underline{\omega}$	ω_0	14.0	131.0
balanced level ω_0	$\overline{\omega}$	6.1	9.3
balanced level ω_0	$\underline{\omega}$	3.1	56.0

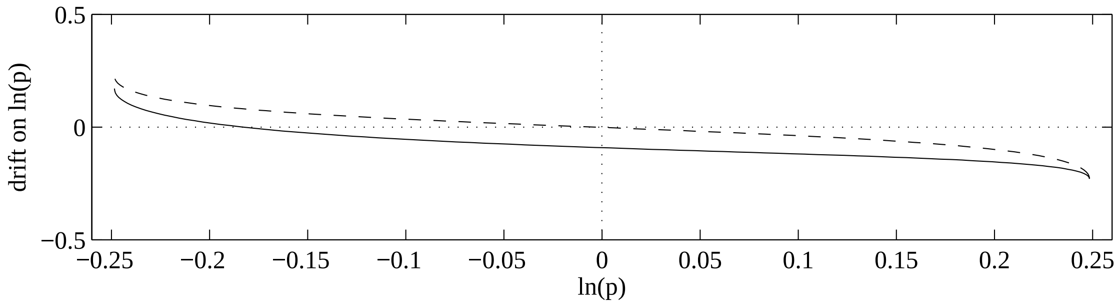
balanced level $\omega_0 = 0$

Figure 1: Drift and Diffusion of Price Process, Effect of Relocation Cost



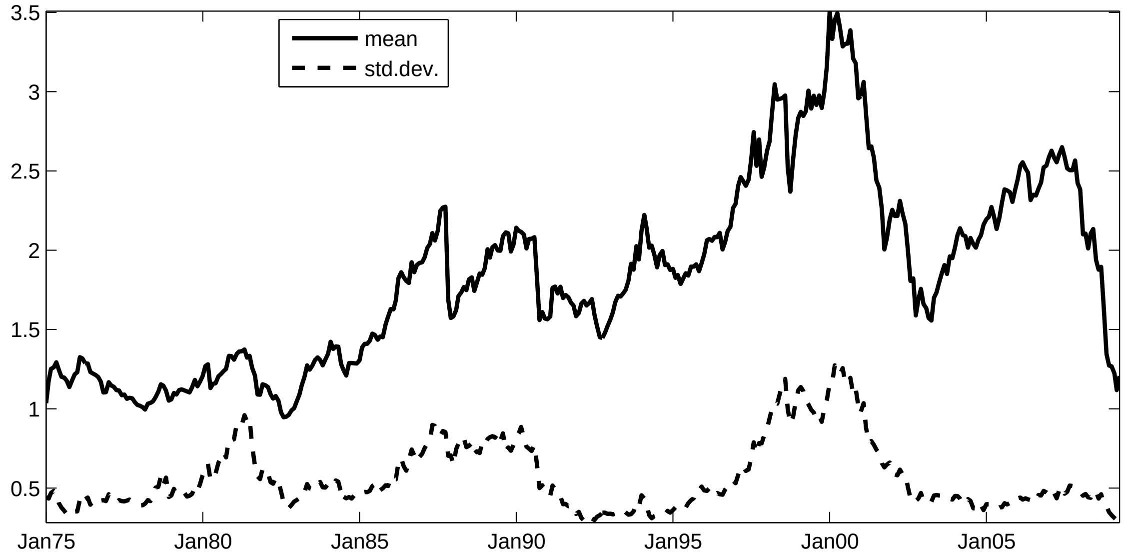
The upper panel shows the drift of the natural logarithm of the real exchange rate process as a function of the natural logarithm of the current real exchange rate, $ln(p)$. The lower panel shows the corresponding (signed) diffusion. It compares the process for a low relocation cost ($r = 0.88$, solid line) with the process for a high relocation cost ($r = 0.78$, dashed line). The other parameter values used for this graph are $\gamma = -0.5$, $\rho = 0.07$, $q = 0.9$, $\alpha = \alpha^* = 0.18$, and $\sigma_{11} = \sigma_{22} = 0.59$.

Figure 2: Drift of Price Process, Effect of Productivity Differences



The graph 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 dashed line shows the process for the case when both countries are largely identical ($\alpha = \alpha^* = 0.18$). The solid line obtains if country 1 has a higher productivity than country 2 ($\alpha = 0.39 > \alpha^* = 0.18$). The other parameter values used for this graph are $\gamma = -0.5$, $\rho = 0.07$, $q = 0.9$, $r = 0.78$, $\sigma_{11} = \sigma_{22} = 0.59$.

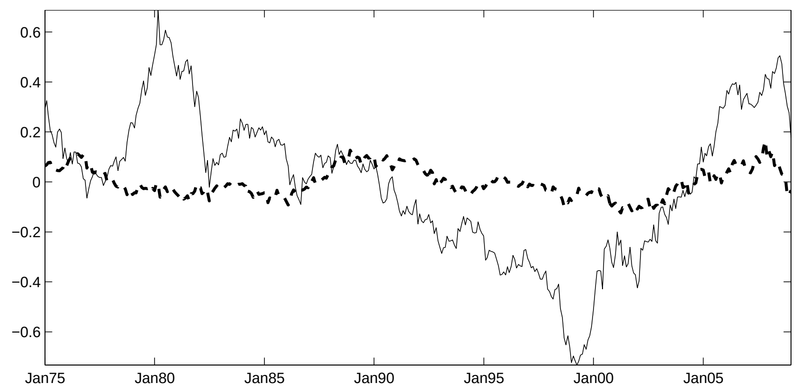
Figure 3: Average and Standard Deviation of Market-to-Book Ratios Across Countries



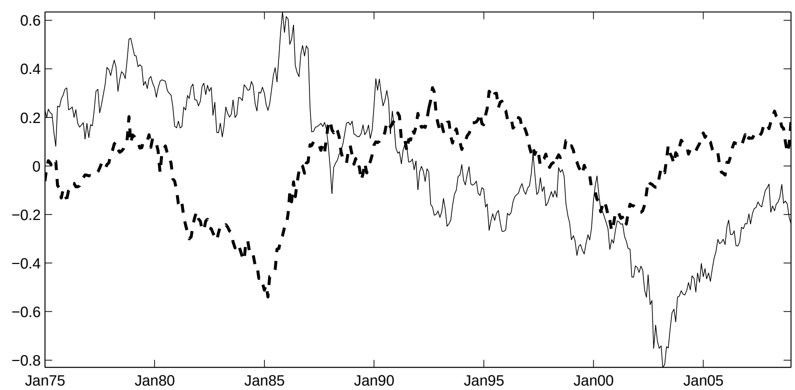
The graph shows the cross-section equal-weight mean and standard deviation of the market-to-book value for all 153 country pairs for the period 1974:12-2008:12.

Figure 4: Real Exchange Rates, 1974–2008

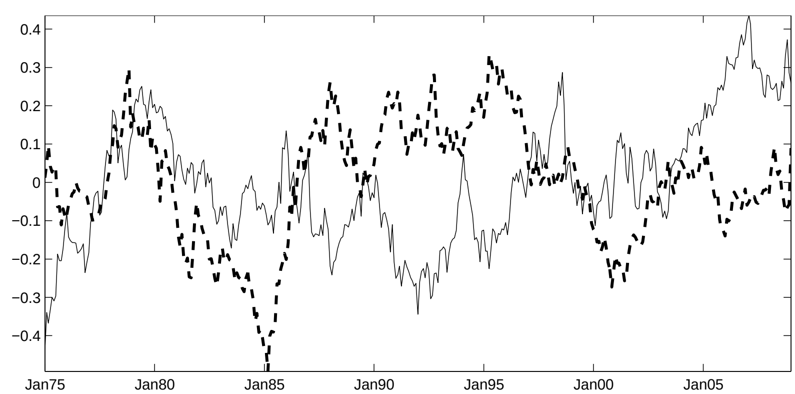
(a) Canada–USA



(b) Germany–USA



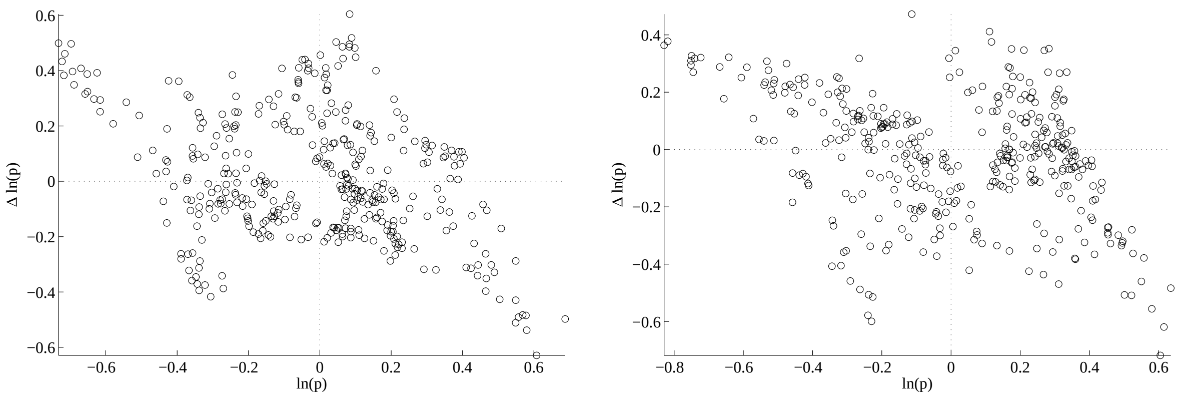
(c) UK–USA



The graphs show the natural logarithm of the real exchange rate for productive capabilities (solid line), and for final goods (dashed line), for the time period 1974:12–2008:12.

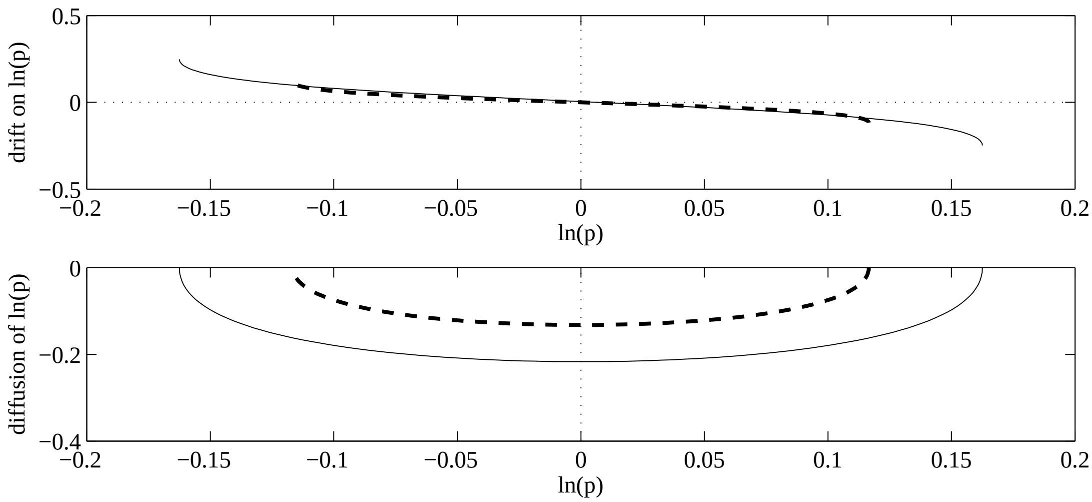
Figure 5: 24-month Changes in Real Exchange Rate of Productive Capabilities vs. Initial Levels

(a) Canada–USA (b) Germany–USA



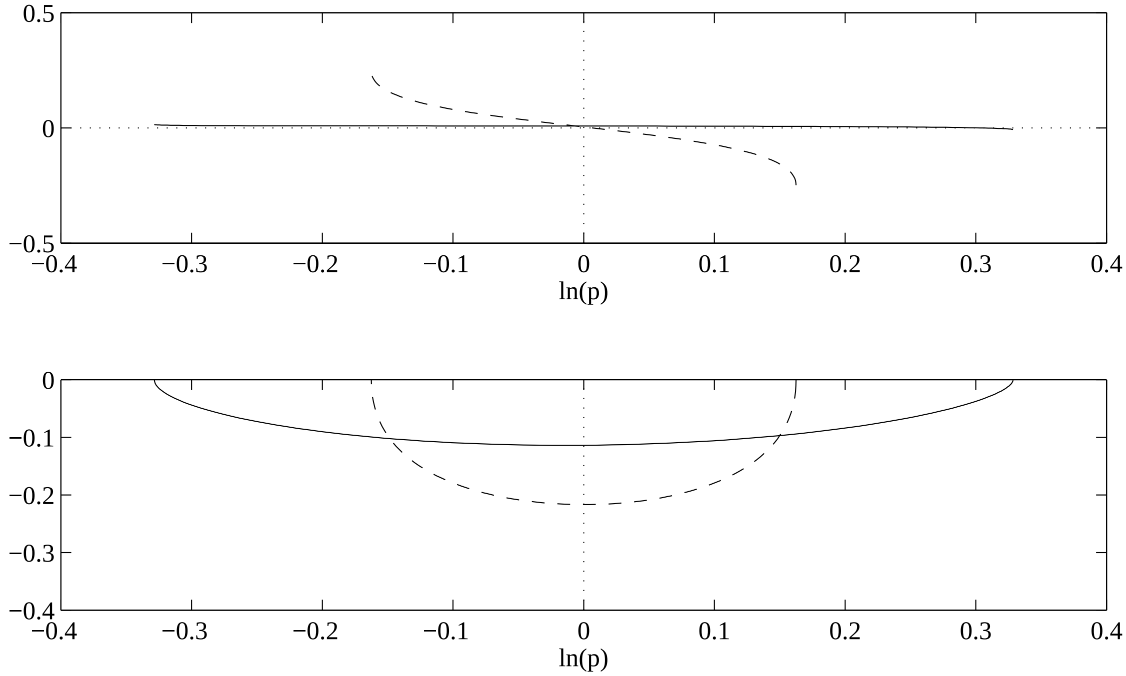
The graphs show the changes in the log real exchange rate of productive capabilities in the two years following a given level for the country pairs Canada-USA and Germany-USA during the period 1974:12-2008:12.

Figure 6: Drift and Diffusion of Real Exchange Rate, Final Goods vs. Productive Capabilities, Germany–USA



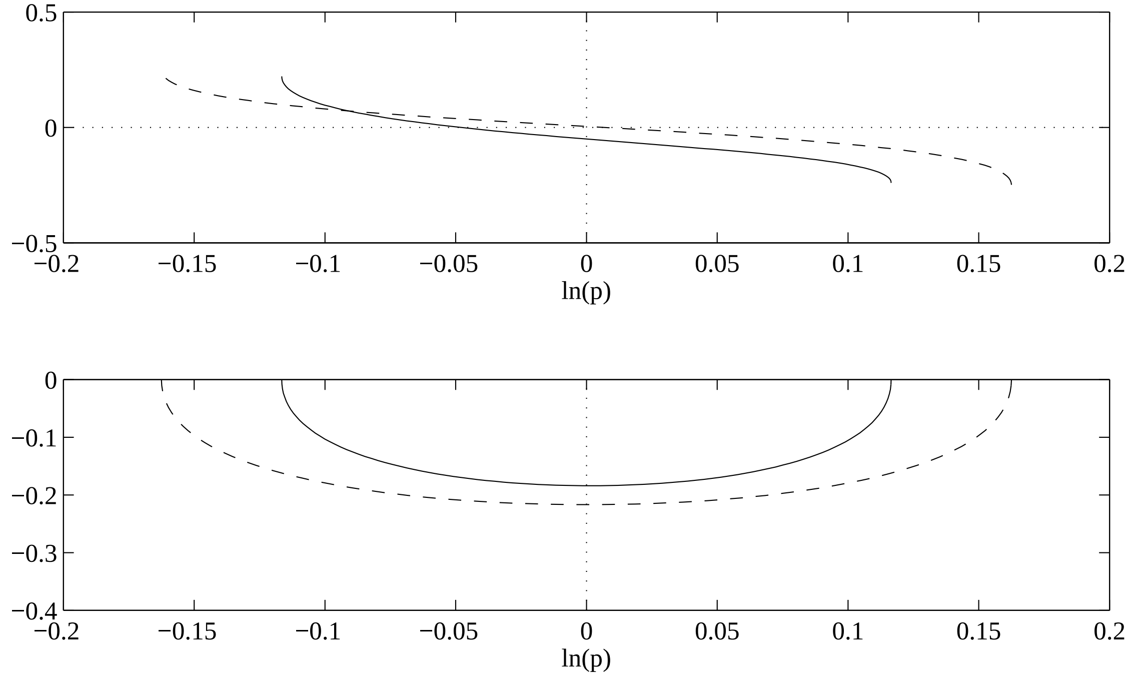
The graph plots the estimated drift and diffusion of the real exchange rate process, based on final goods (dashed line) and based on productive capabilities (solid line), for the pair Germany–USA during the period 1974:12–2008:12. Parameter values are taken from tables 10 and 11. The range of sustainable imbalances for final goods is $\omega \in [0.42; 2.36]$, and for productive capabilities $\omega \in [0.34; 2.51]$.

Figure 7: Drift and Diffusion of Real Exchange Rate based on Productive Capabilities, Japan–USA



The solid line is the estimated drift and diffusion of the real exchange rate of productive capabilities for the country pair Japan–USA during the period 1974:12–2008:12. The dashed line plots the same for Germany–USA. Parameter values are taken from tables 10 and 11. The range of sustainable imbalances is $\omega \in [0.23; 1.84]$.

Figure 8: Drift and Diffusion of Real Exchange Rate based on Productive Capabilities, UK–USA



The solid line is the estimated drift and diffusion of the real exchange rate for productive capabilities for the country pair UK–USA during the period 1974:12–2008:12. The dashed line plots the same for Germany–USA. Parameter values are taken from tables 10 and 11. The range of sustainable imbalances is $\omega \in [0.82; 4.80]$.

Figure 9: Relocation Costs of Final Goods vs. Productive Capabilities

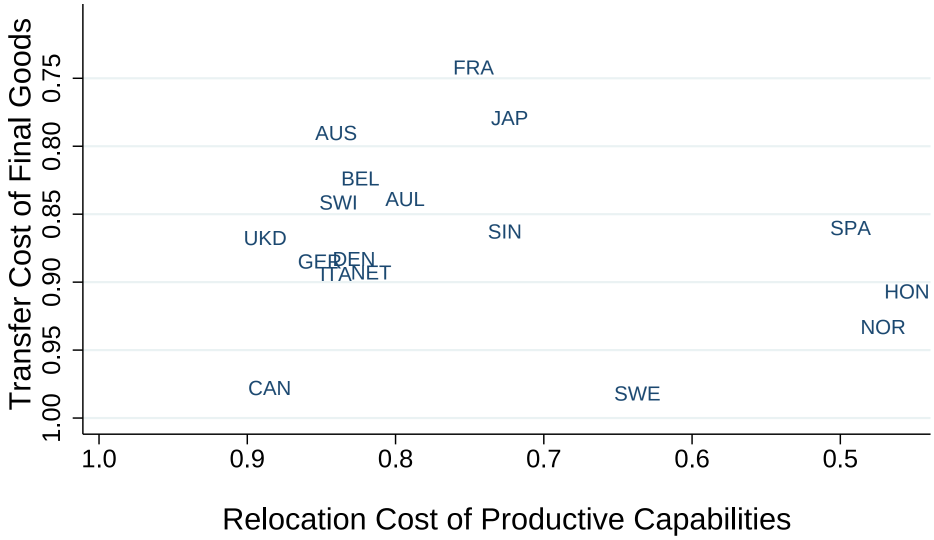
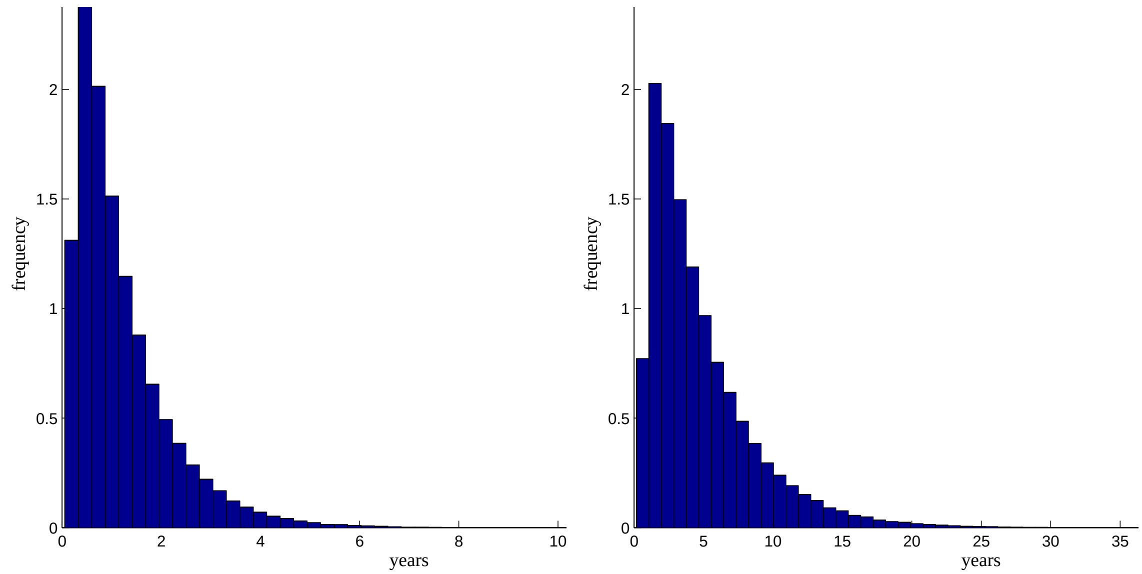
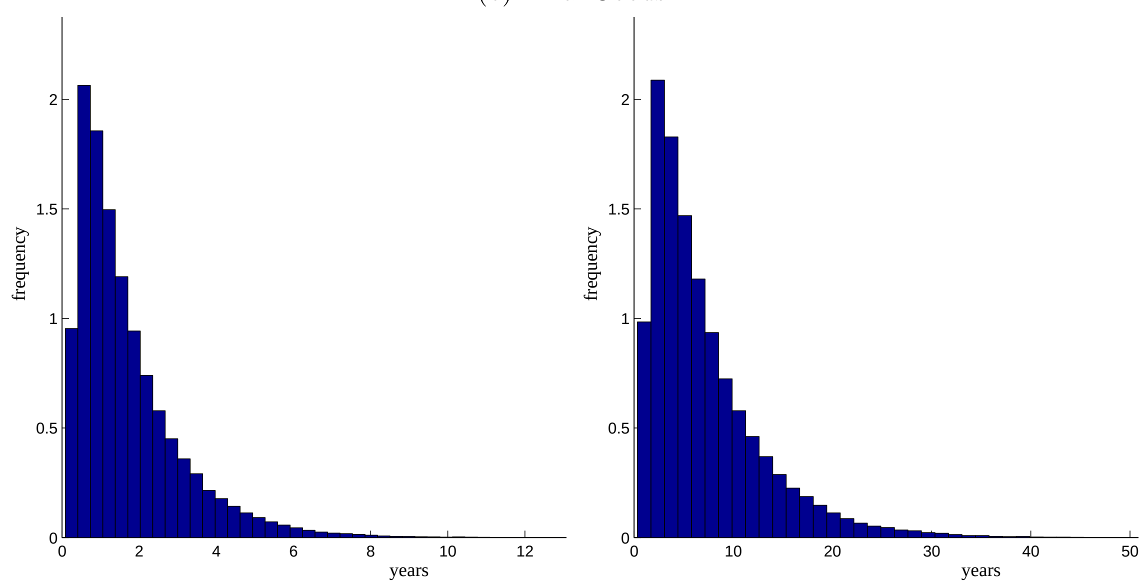


Figure 10: Hittime Distribution for Productive Capabilities, Germany–USA

(a) Productive Capabilities



(b) Final Goods



The histograms show the distribution of the time span until the real exchange rate process reaches a certain level ("hittime distribution"). The upper panels show the hittime distribution of the real exchange rate process for productive capabilities, the lower panels of the real exchange rate process for final goods. The left panels record the first hit of any boundary, when the process starts from a balanced position ($\omega_0 = \sqrt{\overline{\omega}\underline{\omega}}$). The right panels show the first hit of the lower boundary $\underline{\omega}$, when the process starts from the upper boundary $\overline{\omega}$. Each histogram is based on 120000 simulated sample paths with the parameter values taken from tables 10 and 11. Frequencies are measured in 10^4 hits.

A A Model with Trade due to Specialization and Trade due to Arbitrage

This appendix presents a two-country model in which goods are traded for two different reasons. The global undifferentiated good K is produced in both countries, and is traded for arbitrage reasons, whereas the local goods A and B are produced only in country A and B respectively, and are traded due to complete specialization combined with love-of-variety in both countries. Goods located in country B are marked with an asterisk.

$$V(K,K^*,A,A^*,B,B^*) = \max_{\substack{c(t),c^*(t),\\ \Xi(r)}} E_0 \int_0^\infty e^{-\rho u}\left(\frac{q}{\gamma}c_K(u)^\gamma c_A(u)^\gamma c_B(u)^\gamma + \frac{2-q}{\gamma}c_K^*(u)^\gamma c_A^*(u)^\gamma c_B^*(u)^\gamma\right)du$$

s.t.

$$\begin{aligned}
dK(t) &= [\alpha_K K(t) - c_K(t)]\,dt + K(t)\sigma dz(t) - dX_K(t) + r dX_K^*(t)\\
dA(t) &= [\alpha_A A(t) - c_A(t)]\,dt - dX_A(t) + r dX_A^*(t)\\
dB(t) &= -c_B(t)dt - dX_B(t) + r dX_B^*(t)
\end{aligned}$$

$$\begin{aligned}
dK^*(t) &= [\alpha_K^* K^*(t) - c_K^*(t)]\,dt + K^*(t)\sigma dz^*(t) + r dX_K(t) - dX_K^*(t)\\
dA^*(t) &= -c_A^*(t)dt + r dX_A(t) - dX_A^*(t)\\
dB^*(t) &= [\alpha_B B^*(t) - c_B^*(t)]\,dt + r dX_B(t) - dX_B^*(t)
\end{aligned}$$

Storing good B in country A yields no return, it is merely consumed there. Thus absent any fixed cost of shipping and $\alpha_B > 0$ the optimal allocation implies no shipment of good B from country A to B ($dX_B = 0$), hence $r dX_B^* = c_B dt$ and $dB = 0$. Analogously $dX_A^* = 0$, $r dX_A = c_A^* dt$, $dA^* = 0$, and $dA = \left(\alpha_A A - c_A - \frac{1}{r}c_A^*\right)dt$. Thus under an optimal consumption plan, goods A and B are shipped at every instant to satisfy the consumption need in the other country. The real exchange rate for these two goods is fixed, for good A $\frac{V_A}{V_{A^*}} = \frac{V_A}{rV_A} = \frac{1}{r}$ and for good B $\frac{V_B}{V_{B^*}} = r$ hold always. Thus for goods which are traded for specialization reasons, there is no time variation in the real exchange rate. As part of an aggregate real exchange rate composed of many goods, these goods affect only the average exchange rate, e.g. the long-run PPP level.

To the contrary, good K is shipped only if due to random shocks this good becomes very differently valued in the two countries. This trade for arbitrage reasons comes with a systematic time variation in real exchange rates, as shown by equation 25 in the following appendix. Because goods A and B contribute nothing to the time-variation of exchange rates, on which our identification approach rests, we drop these goods from our model, and focus our model on goods with arbitrage trade only.

B Characterization of the Model

In this appendix we discuss and solve an extension of Dumas (1992). In particular, we introduce nonzero covariance between the country-specific shocks and country-specific productivity.

B.1 General Model

Suppose z and z^* are two standard Brownian motion processes[35] and Ω is a positive definite and symmetric matrix.

$$\begin{pmatrix} d\tilde{z} \\ d\tilde{z}^* \end{pmatrix} = \Omega \begin{pmatrix} dz \\ dz^* \end{pmatrix} = \begin{pmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{12} & \sigma_{22} \end{pmatrix} \begin{pmatrix} dz \\ dz^* \end{pmatrix} = \begin{pmatrix} \sigma_{11}dz + \sigma_{12}dz^* \\ \sigma_{12}dz + \sigma_{22}dz^* \end{pmatrix} \tag{10}$$

Plugging this process of productivity shocks and the first order conditions for c into the Hamilton-Jacobi partial differential equation implies that capital stocks K and K^* follow the differential equation

$$\begin{aligned} 0 = & \frac{1-\gamma}{\gamma} q^{\frac{1}{1-\gamma}} V_K^{\frac{\gamma}{\gamma-1}} + \frac{1-\gamma}{\gamma}(2-q)^{\frac{1}{1-\gamma}} V_{K^*}^{\frac{\gamma}{\gamma-1}} - \rho V \\ & + V_K \alpha K + V_{K^*}\alpha^* K^* + \frac{1}{2} V_{KK}\sigma_{11}^2 K^2 + V_{KK^*}\sigma_{12}^2 K K^* + \frac{1}{2} V_{K^*K^*}\sigma_{22}^2 K^{*2}. \end{aligned}$$

Using $V(K, K^*) = K^{*\gamma} I(\omega)$, the capital imbalance $\omega = K/K^*$ then follows the differential equation

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

[35] dz and dz^* may be called white noise with $dz \sim N(0,1)$, $dz^* \sim N(0,1)$

$$+ \quad \left[\frac{1}{2}\left(\sigma_{11}^2+\sigma_{12}^2\right)+\frac{1}{2}\left(\sigma_{22}^2+\sigma_{12}^2\right)-\sigma_{12}(\sigma_{11}+\sigma_{22})\right]\omega^2 I''(\omega)\,. \tag{11}$$

For estimation we use $\sigma_{12} = 0$ and $\sigma_{11} = \sigma_{22} = \sigma$, which leads to equation (2) in the main text. In the symmetric case $\alpha = \alpha^*$, $\sigma_{11} = \sigma_{22} = \sigma$, $q = 1$, and equation (11) reduces to

$$\begin{aligned} 0 \;&=\; \frac{1-\gamma}{\gamma} I'(\omega)^{\frac{\gamma}{\gamma-1}} + \frac{1-\gamma}{\gamma}\left[\gamma I(\omega) - \omega I'(\omega)\right]^{\frac{\gamma}{\gamma-1}} \\ &+\; (\alpha\gamma-\rho)I(\omega) + \frac{1}{2}\gamma(\gamma-1)(\sigma^2+\sigma_{12}^2)I(\omega) \\ &-\; (\gamma-1)(\sigma-\sigma_{12})^2\omega I'(\omega) + (\sigma-\sigma_{12})^2\omega^2 I''(\omega)\,. \end{aligned} \tag{12}$$

The last three terms capture the effect of a nonzero covariance.

B.2 Model Solution

Optimal choice of the two boundaries of $\Xi(r)$ requires that the good's valuation, as well as the marginal valuation before and after a relocation must be equal. This imposes three boundary conditions on each side of the differential equation. For the upper boundary these conditions are

$$V_K(K,K^*) = rV_{K^*}(K,K^*), \tag{13}$$

$$V_{KK}(K,K^*) = rV_{KK^*}(K,K^*), \tag{14}$$

$$V_{K^*K}(K,K^*) = rV_{K^*K^*}(K,K^*). \tag{15}$$

By homogeneity of the value function, the latter two conditions are identical. These conditions can be rewritten in terms of $I(\omega)$ as

$$\begin{aligned} I(\overline{\omega}) \;&=\; \frac{1}{\gamma}(1+r\overline{\omega})^{\gamma}\left[(1-\gamma)\,q^{\frac{1}{1-\gamma}} r^{\frac{\gamma}{\gamma-1}} + (1-\gamma)\,(2-q)^{\frac{1}{1-\gamma}}\right]^{1-\gamma} \\ \times\;& \Bigg\{\rho-\alpha^*\gamma-\frac{1}{2}(\sigma_{12}^2+\sigma_{22}^2)(\gamma-1)\gamma \\ -\;& \frac{r\overline{\omega}\gamma}{1+r\overline{\omega}}\left[\alpha-\alpha^*+(\gamma-1)(-\sigma_{22}^2-\sigma_{12}^2-\sigma_{12}(\sigma_{11}+\sigma_{22}))\right] \\ -\;& \frac{r^2\overline{\omega}^2\gamma(\gamma-1)}{(1+r\overline{\omega})^2}\left[\frac{1}{2}\left(\sigma_{11}^2-\sigma_{12}^2\right)+\frac{1}{2}\left(\sigma_{22}^2-\sigma_{12}^2\right)-\sigma_{12}(\sigma_{11}+\sigma_{22})\right]\Bigg\}^{\gamma-1}, \end{aligned} \tag{16}$$

$$\frac{I'(\overline{\omega})}{\gamma I(\overline{\omega})} = \frac{r}{1+r\overline{\omega}}, \tag{17}$$

and

$$\frac{I''(\overline{\omega})}{\gamma I(\overline{\omega})} = \frac{r^2(\gamma-1)}{(1+r\overline{\omega})^2}. \tag{18}$$

For the lower boundary we have, analogously,

$$\begin{aligned} I(\underline{\omega}) &= \frac{1}{\gamma}\left(r+\underline{\omega}\right)^{\gamma}\left[(1-\gamma)\,q^{\frac{1}{1-\gamma}} + (1-\gamma)\,(2-q)^{\frac{1}{1-\gamma}}\,r^{\frac{\gamma}{\gamma-1}}\right]^{1-\gamma} \\ &\times \left\{\rho-\alpha^*\gamma-\frac{1}{2}(\sigma_{12}^2+\sigma_{22}^2)(\gamma-1)\gamma\right. \\ &- \frac{\underline{\omega}\gamma}{r+\underline{\omega}}\left[\alpha-\alpha^*+(\gamma-1)(-\sigma_{22}^2-\sigma_{12}^2-\sigma_{12}(\sigma_{11}+\sigma_{22}))\right] \\ &- \left.\frac{\underline{\omega}^2\gamma(\gamma-1)}{(r+\underline{\omega})^2}\left[\frac{1}{2}\left(\sigma_{11}^2-\sigma_{12}^2\right)+\frac{1}{2}\left(\sigma_{22}^2-\sigma_{12}^2\right)-\sigma_{12}(\sigma_{11}+\sigma_{22})\right]\right\}^{\gamma-1}, \end{aligned}$$

$$\frac{I'(\underline{\omega})}{\gamma I(\underline{\omega})} = \frac{1}{1+r\underline{\omega}}, \tag{19}$$

and

$$\frac{I''(\underline{\omega})}{\gamma I(\underline{\omega})} = \frac{\gamma-1}{(r+\underline{\omega})^2}. \tag{20}$$

In the symmetric case $\alpha=\alpha^*$, $\sigma_{11}=\sigma_{22}=\sigma$, and $q=1$, with $\sigma_{12}=0$, we have $\overline{\omega}=1/\underline{\omega}=\lambda$, $I(\overline{\omega})=\overline{\omega}^{\gamma}I\left(\underline{\omega}\right)$, and (16) reduces to

$$I(\lambda) = \frac{(1+r\lambda)^{\gamma}}{\gamma}\left(1+r^{\frac{\gamma}{\gamma-1}}\right)^{1-\gamma}\left(\frac{\rho-\alpha\gamma}{1-\gamma}+\frac{\sigma^2\gamma}{2}\cdot\frac{1+r^2\lambda^2}{(1+r\lambda)^2}\right)^{\gamma-1}. \tag{21}$$

Applying Ito's formula for multiple standard processes we obtain the process of the capital imbalance ω inside of Ξ

$$\begin{aligned} d\omega &= \left[-\frac{c(t)}{K(t)}+\frac{c^*(t)}{K^*(t)}-\sigma_{12}(\sigma_{11}+\sigma_{22})+\sigma_{12}^2+\sigma_{22}^2+\alpha-\alpha^*\right]\omega dt \\ &+ (\sigma_{11}-\sigma_{12})\omega dz-(\sigma_{22}-\sigma_{12})\,\omega dz^*, \end{aligned} \tag{22}$$

which in terms of $I(\omega)$ can be written as

$$\begin{aligned} d\omega &= \left(-\frac{1}{\omega}\left(\frac{I'(\omega)}{q}\right)^{\frac{1}{\gamma-1}}+\left(\frac{\gamma I(\omega)-\omega I'(\omega)}{2-q}\right)^{\frac{1}{\gamma-1}}-\sigma_{12}(\sigma_{11}+\sigma_{22})+\sigma_{12}^2+\sigma_{22}^2+\alpha-\alpha^*\right)\omega dt \\ &+ \sqrt{(\sigma_{11}-\sigma_{12})^2+(\sigma_{22}-\sigma_{12})^2}\omega dz', \end{aligned} \tag{23}$$

where z' is again standard Brownian motion.

From (22), using $p(\omega) = \frac{V_K}{V_{K^*}} = \frac{I'(\omega)}{\gamma I(\omega) - \omega I'(\omega)}$ the process dp can be written as a function of ω, $I(\omega)$, $I'(\omega)$, $I''(\omega)$, and $I'''(\omega)$. The process for $ln(p)$ is

$$\begin{aligned}
& dln(p(\omega)) \\
= \;& dt \Bigg\{ \left[-\frac{c}{K} + \frac{c^*}{K^*} + \alpha - \alpha^* + \sigma_{12}^2 + \sigma_{22}^2 - \sigma_{12}(\sigma_{11} + \sigma_{22}) \right] \left[\frac{I''}{I'} - \frac{(\gamma-1)I' - \omega I''}{\gamma I - \omega I'} \right] \omega \\
+ \;& \frac{(\sigma_{11} - \sigma_{12})^2 + (\sigma_{12} - \sigma_{22})^2}{2} \\
\times \;& \left[\frac{I''' I' - I''^2}{I'^2} - \frac{((\gamma-2)I'' - \omega I''')(\gamma I - \omega I') - ((\gamma-1)I' - \omega I'')^2}{(\gamma I - \omega I')^2} \right] \omega^2 \Bigg\} \\
+ \;& dz' \sqrt{(\sigma_{11} - \sigma_{12})^2 + (\sigma_{12} - \sigma_{22})^2} \left[\frac{I''}{I'} - \frac{(\gamma-1)I' - \omega I''}{\gamma I - \omega I'} \right] \omega. \qquad (24)
\end{aligned}$$

The optimality conditions (13), (14), (15), and their counterparts for the lower boundary directly imply that the price level at both boundaries is identical, even if $\overline{\omega} \neq 1/\underline{\omega}$. At the upper boundary $\overline{\omega}$, for example, we calculate

$$p(\overline{\omega}) = \frac{I'(\overline{\omega})}{\gamma I(\overline{\omega}) - \overline{\omega} I'(\overline{\omega})} = \frac{\frac{r\gamma}{1+r\overline{\omega}}}{\gamma - \overline{\omega}\frac{r\gamma}{1+r\overline{\omega}}} = r.$$

In the symmetric case ($\alpha = \alpha^*$, $\sigma_{11} = \sigma_{22} = \sigma$, and $q = 1$) equation (23) reduces to

$$\begin{aligned}
d\omega \;=\;& \left(-\frac{1}{\omega} I'(\omega)^{\frac{1}{\gamma-1}} + (\gamma I(\omega) - \omega I'(\omega))^{\frac{1}{\gamma-1}} + (\sigma - \sigma_{12})^2 \right) \omega dt \\
+ \;& \sqrt{2}(\sigma - \sigma_{12}) \omega dz'.
\end{aligned}$$

Utilizing the useful property of the symmetric case that $I'(1) = \frac{\gamma}{2} I(1)$, we find that at $\omega = 1$ the differential equation (12) implies

$$\begin{aligned}
0 \;=\;& (1-\gamma) I'(1)^{\frac{1}{\gamma-1}} \\
+ \;& \alpha\gamma - \rho + \gamma(\gamma-1)\sigma\sigma_{12} + (\sigma - \sigma_{12})^2 \frac{I''(1)}{I(1)}.
\end{aligned}$$

Simplifying further by setting $\sigma_{12} = 0$, the price process (24) reduces to

$$\begin{aligned}
& dln(p(\omega)) \\
& = dt \Bigg\{ \left[-\frac{c}{K} + \frac{c^*}{K^*} + \sigma^2 \right] \left[\frac{I''}{I'} - \frac{(\gamma-1)I' - \omega I''}{\gamma I - \omega I'} \right] \omega
\end{aligned}$$

$$+\sigma^2\left[\frac{I'''I'-I''^2}{I'^2}-\frac{((\gamma-2)I''-\omega I''')(\gamma I-\omega I')-((\gamma-1)I'-\omega I'')^2}{(\gamma I-\omega I')^2}\right]\omega^2\Bigg\}$$

$$+dz'\sigma\sqrt{2}\left[\frac{I''}{I'}-\frac{(\gamma-1)I'-\omega I''}{\gamma I-\omega I'}\right]\omega. \tag{25}$$

This special case allows calculating the exact value of the price level at $\omega = 1$ by

$$p(1)=\frac{\frac{\gamma}{2}}{\gamma-\frac{\gamma}{2}}=1.$$

B.3 Drift of Real Exchange Rate at the Boundary

We calculate the drift of the real exchange rate, $ln(p)$, at the boundary. Let $\overline{\omega} > 1$ denote the upper imbalance level. One can show that the drift of $dln(p) = \mu_p(p)dt + \sigma_p(p)dz$ at $\omega = \overline{\omega}$ with $\sigma_{11} = \sigma_{22} = \sigma$ and $\sigma_{12} = 0$ is

$$\mu_p(r)=\sigma^2\overline{\omega}^2\left[\frac{I'''(\overline{\omega})}{I'(\overline{\omega})}(1+r\overline{\omega})-(\gamma-1)(\gamma-2)\frac{r^2}{1+r\overline{\omega}}\right].$$

Further,

$$\frac{I'''(\overline{\omega})}{I'(\overline{\omega})}=\frac{\gamma-1}{\overline{\omega}^2(1+r\overline{\omega})^2}\left[r^2\overline{\omega}^2(\gamma-2)-r\overline{\omega}+1-\frac{1+r\overline{\omega}}{\gamma-1}\frac{\alpha-\alpha^*}{\sigma^2}\right].$$

Therefore the drift of $ln(p)$ at $\omega = \overline{\omega}$ simplifies to

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

Note that the drift at the boundary depends on ρ only indirectly via $\overline{\omega}$, but directly on the productivity differential $\Delta\alpha = \alpha - \alpha^*$. At $\omega = \overline{\omega} > 1$ we have $V_K < V_{K^*}$ and therefore $p(\lambda) = \frac{V_K}{V_{K^*}} < 1$. For mean reversion to hold we need therefore a positive drift of p, which requires at $\alpha = \alpha^*$ that $1 - r\overline{\omega} < 0$ and therefore $\overline{\omega} > \frac{1}{r}$.[36]

[36] The values for $\overline{\omega}$ in table 1 show that $\forall\gamma < 0\ \exists\sigma_0(\gamma)$ s.t. $\forall\sigma < \sigma_0(\gamma)$ the process of $ln(p)$ is in fact divergent.

C Inflation Adjustment of Book Values

Book values record the value of capital goods and productive capabilities at the time of acquisition or production by the firm. In order to properly measure the current value of these goods, that is, in order to match the overall inflation reflected in the market values, we correct the book values for inflation. Figure 11 shows the effect of this inflation correction for Germany, Japan and the USA.

Our correction procedure adjusts the original bookvalues (dashed line) for Germany upwards only in the high inflation periods of the 1970s. The new series is shown by the solid line. Persistent inflation periods lead to a substantial upward adjustment in bookvalues, as in the case of the USA in the late 1970s in the lower panel of figure 11. A deflation, as in Japan in the 1990s, has the opposite effect. The corrected book values for Japan in the middle panel of figure 11 are smaller than the original ones.

[Figure 11 about here.]

D Real Exchange Rate Data

Figures 12, 13, and 14 show the natural logarithm of the real exchange rate series in our dataset. The solid line represents the real exchange rate for for productive capabilities, and the dashed line the real exchange rate for final goods.

[Figure 12 about here.]

[Figure 13 about here.]

[Figure 14 about here.]

E Nonlinearity Test

We test the null hypothesis of linearity against the alternative of ESTAR-type nonlinearity using a heteroskedasticity-consistent Lagrange-multiplier-type test (Granger & Teräsvirta 1993, Teräsvirta 1994, Franses & van Dijk 2000). For a given transition variable p_{t-d} the test is based on a second order Taylor approximation of the ESTAR model (9)

$$p_t = \beta_0 + \beta_1 q_{t-1} + \beta_2 q_{t-1} p_{t-d} + \beta_3 q_{t-1} p_{t-d}^2 + \varepsilon_t, \tag{26}$$

where $q_{t-1} = (p_{t-1}, p_{t-2}, \ldots, p_{t-m})$ denotes the vector of independent AR(m) variables and β_0, β_1, β_2 and β_3 are functions of the parameters of the ESTAR model. The null hypothesis of linearity is then $H_0 : \beta_2 = \beta_3 = 0$. A heteroskedasticity-robust test statistic is

$$F = \frac{T - 3m - 1}{2mT} \mathbf{1}' DR(R'R)^{-1} R'D'\mathbf{1}, \tag{27}$$

where $\mathbf{1} = (1, \ldots, 1)'$, D is a $T \times T$ matrix with the residuals from the linear model on the diagonal, and the matrix R contains the residuals from the regression of the $2m$ interaction terms in (26) on $(1\ q_{t-1})$. Under the null hypothesis this test statistic is approximately $F(2m, T - 3m - 1)$ distributed.

We determine the lag, d, of the transition variable as the lag which leads to the strongest rejection of linearity (Teräsvirta 1994). When the significance of rejection is similar for multiple lags, we choose the lowest, and the one that is robust against inclusion of additional AR lags.

F Indirect Inference Results

In this appendix we provide details on the other coefficients besides relocation cost for selected countries. All coefficients except the relocation cost are estimated with large standard errors and serve primarily for fitting the model (tables 10 and 11). The shock variance is typically higher for productive capabilities than for final goods.

[Table 10 about here.]

[Table 11 about here.]

Table 10: Indirect Inference Estimates for Final Goods vs. USA

	r	$\Delta\alpha$	σ	q
Australia	**0.84**	0.31	0.62	1.03
	(0.02)	(4.1)	(1.2)	(45)
Austria	**0.79**	0.16	0.48	0.91
	(0.01)	(0.29)	(0.06)	(5.6)
Belgium	**0.82**	0.13	0.46	1.25
	(0.02)	(0.10)	(0.14)	(4.2)
Canada	**0.98**	0.02	0.16	0.87
	(0.00)	(0.00)	(0.01)	(0.15)
Denmark	**0.88**	0.02	0.47	0.97
	(0.02)	(5.8)	(0.14)	(110)
France	**0.74**	0.01	0.29	1.03
	(0.06)	(0.95)	(0.17)	(21)
Germany	**0.89**	0.00	0.47	1.00
	(0.02)	(7.9)	(0.07)	(120)
Hongkong	**0.91**	-0.00	0.27	0.86
	(0.01)	(0.75)	(0.07)	(19)
Italy	**0.89**	0.04	0.47	1.25
	(0.07)	(27)	(3.5)	(400)
Japan	**0.78**	0.02	0.35	1.08
	(0.02)	(0.02)	(0.05)	(0.85)
Netherlands	**0.89**	0.03	0.51	1.00
	(0.01)	(12)	(0.53)	(210)
Norway	**0.93**	-0.15	0.71	1.15
	(0.01)	(6.5)	(0.96)	(180)
Singapore	**0.86**	-0.03	0.26	0.79
	(0.01)	(0.04)	(0.05)	(0.09)
Spain	**0.86**	0.02	0.44	1.00
	(0.02)	(3.3)	(0.14)	(61)
Sweden	**0.98**	0.00	0.17	1.26
	(0.00)	(0.01)	(0.02)	(0.11)
Switzerland	**0.84**	0.06	0.49	1.28
	(0.02)	(3.3)	(0.62)	(43)
UK	**0.87**	0.05	0.45	1.22
	(0.01)	(2.7)	(0.50)	(37)

WPI, demeaned and deseasonalized, 1974:12–2008:12, $\gamma = -0.5$, $\rho = 0.07$. ESTAR as auxiliary model with $2 \leq p \leq 4$ and $d \leq 12$ chosen by nonlinearity test. Standard errors in parentheses.

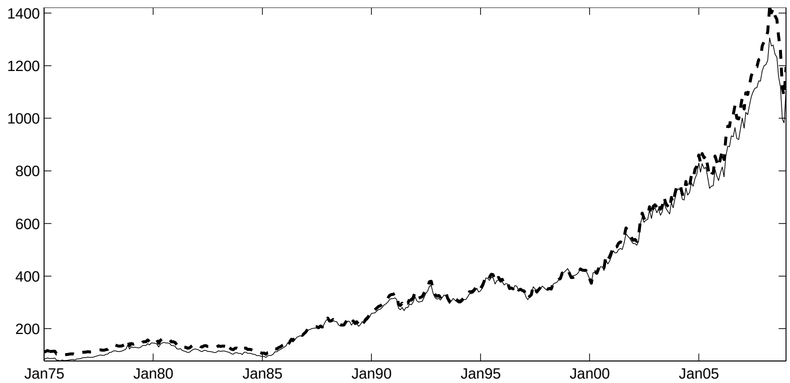
Table 11: Indirect Inference Estimates for Productive Capabilities vs. USA

	r	$\Delta\alpha$	σ	q
Australia	**0.79**	-0.03	0.52	0.80
	(0.02)	(1.5)	(0.17)	(23)
Austria	**0.84**	0.05	0.88	1.07
	(0.05)	(30)	(0.29)	(8800)
Belgium	**0.82**	-0.10	0.71	0.52
	(0.09)	(13)	(1.2)	(490)
Canada	**0.89**	-0.05	0.54	0.83
	(0.02)	(2.5)	(0.29)	(41)
Denmark	**0.83**	-0.06	0.68	0.87
	(0.07)	(14)	(0.97)	(240)
France	**0.75**	-0.01	0.51	0.88
	(0.01)	(0.16)	(0.05)	(1.5)
Germany	**0.85**	-0.02	0.65	0.90
	(0.02)	(6.9)	(0.20)	(170)
Hongkong	**0.46**	0.04	0.52	1.00
	(0.11)	(2.5)	(0.59)	(67)
Italy	**0.84**	-0.02	0.84	0.71
	(0.03)	(11)	(0.13)	(7400)
Japan	**0.72**	-0.01	0.15	0.77
	(0.01)	(0.03)	(0.08)	(0.98)
Netherlands	**0.82**	0.04	0.25	0.99
	(0.00)	(0.01)	(0.01)	(0.04)
Norway	**0.47**	-0.00	0.42	0.67
	(0.02)	(0.07)	(0.05)	(0.66)
Singapore	**0.73**	0.04	0.63	1.32
	(0.04)	(9.4)	(0.76)	(140)
Spain	**0.49**	0.03	0.39	1.36
	(0.73)	(17)	(2.9)	(327)
Sweden	**0.64**	0.14	0.55	0.58
	(0.06)	(0.39)	(0.39)	(6.2)
Switzerland	**0.84**	-0.08	0.58	1.14
	(0.01)	(2.0)	(0.31)	(27)
UK	**0.89**	0.21	0.68	0.99
	(0.00)	(3.1)	(0.67)	(32)

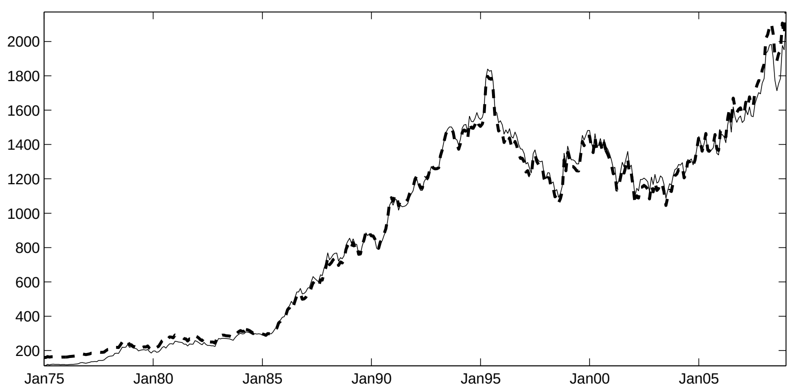
Inflation-adjusted bookvalues, demeaned and deseasonalized, 1974:12–2008:12, $\gamma = -0.5$, $\rho = 0.07$. ESTAR as auxiliary model with $2 \leq p \leq 4$ and $d \leq 12$ chosen by nonlinearity test. Standard errors in parentheses.

Figure 11: Book Value Correction

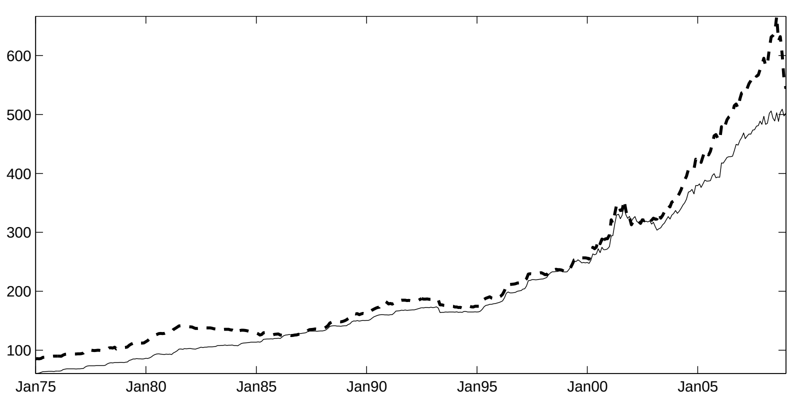
(a) Germany



(b) Japan



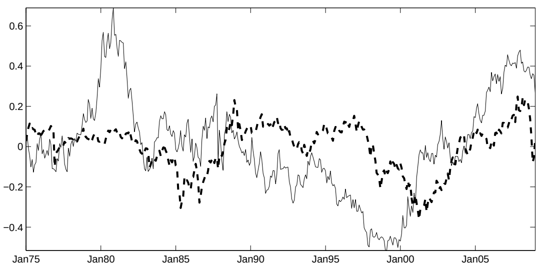
(c) USA



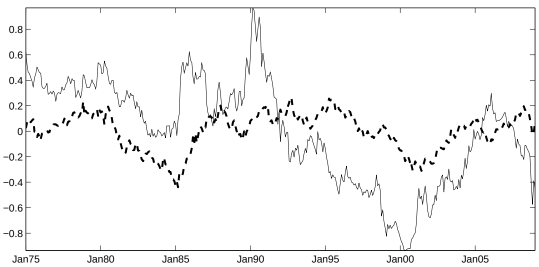
The solid line shows the reported book value for companies included in the respective MSCI country index during 1974:12–2008:12. The dashed line shows the same book value after correcting for inflation.

Figure 12: Real Exchange Rates, 1974-2008

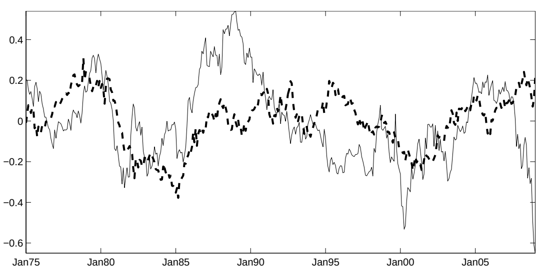
(a) Australia–USA



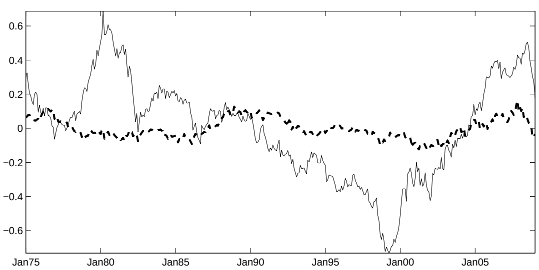
(b) Austria–USA



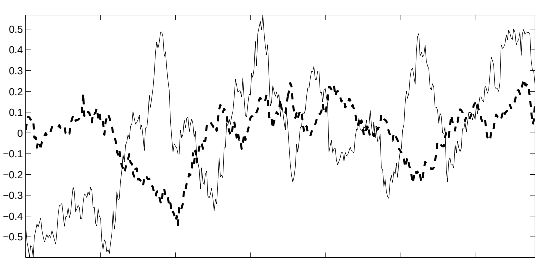
(c) Belgium–USA



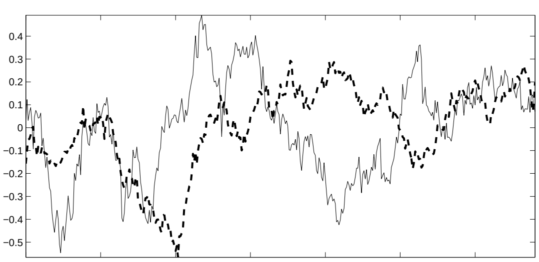
(d) Canada–USA



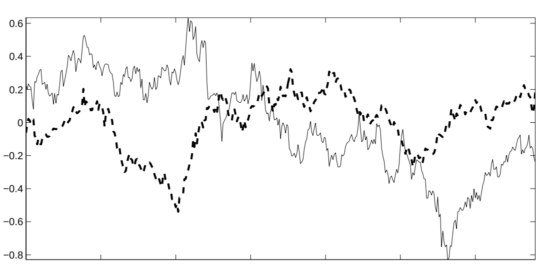
(e) Denmark–USA



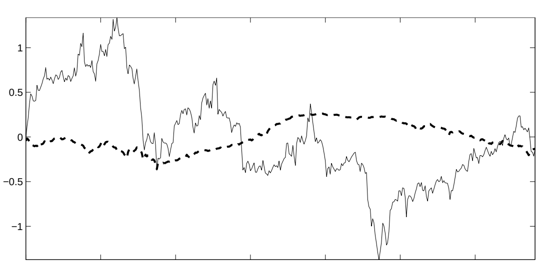
(f) France–USA



(g) Germany–USA



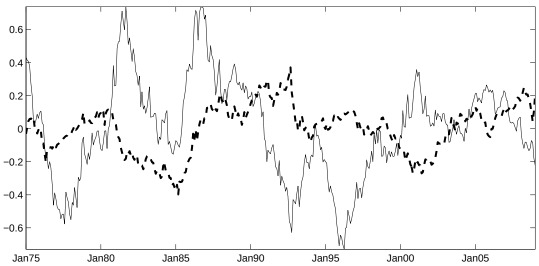
(h) Hongkong–USA



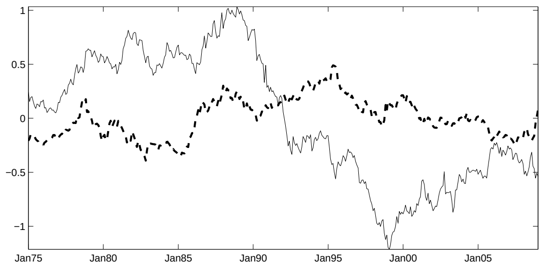
The graphs show the natural logarithm of the real exchange rate for productive capabilities (solid line), and for final goods (dashed line), for the period 1974:12-2008:12.

Figure 13: Real Exchange Rates, 1974-2008 (continued)

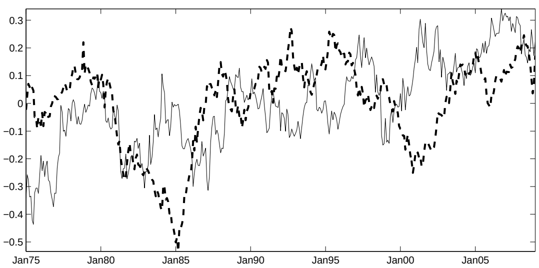
(a) Italy–USA



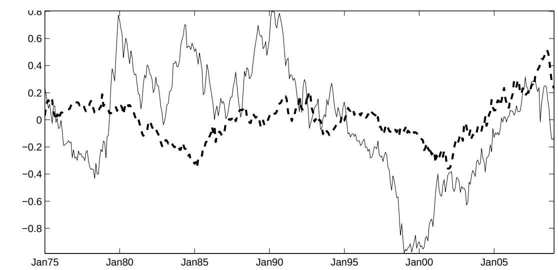
(b) Japan–USA



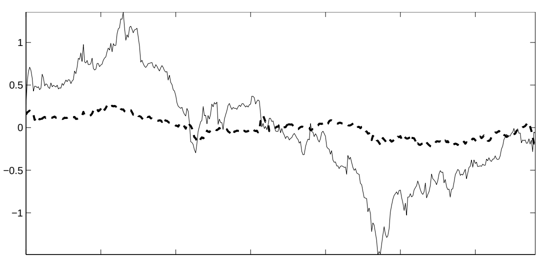
(c) Netherland–USA



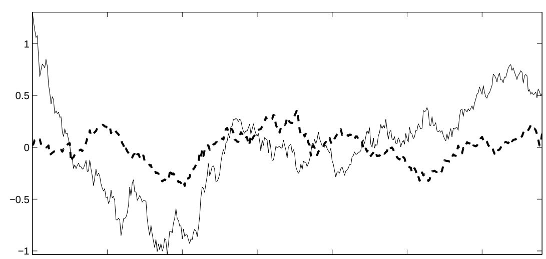
(d) Norway–USA



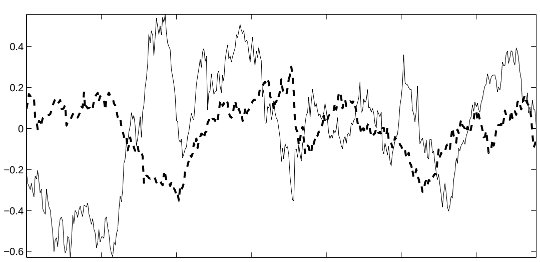
(e) Singapore–USA



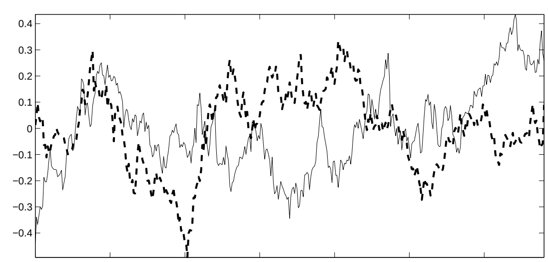
(f) Spain–USA



(g) Sweden–USA



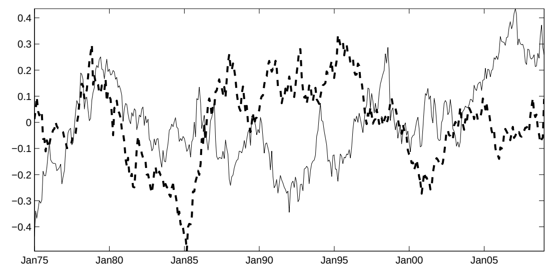
(h) Switzerland–USA



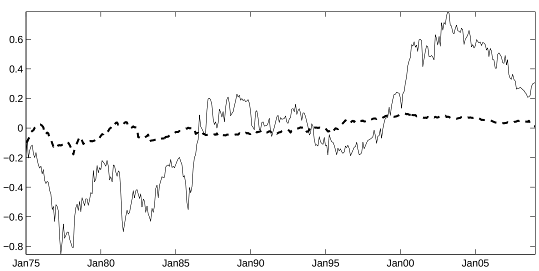
The graphs show the natural logarithm of the real exchange rate for productive capabilities (solid line), and for final goods (dashed line), for the period 1974:12-2008:12.

Figure 14: Real Exchange Rates, 1974-2008 (continued)

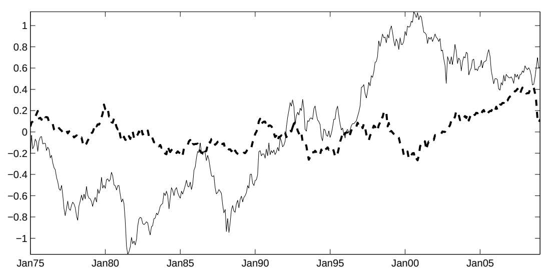
(a) United Kingdom–USA



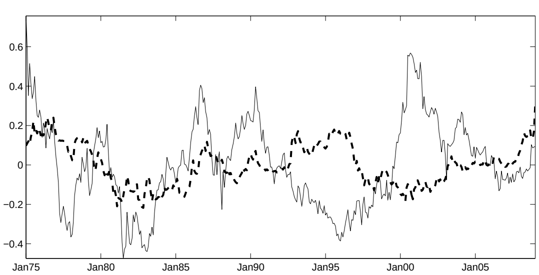
(b) France–Germany



(c) France–Japan

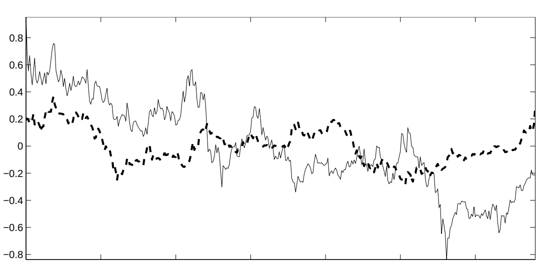


(d) France–United Kingdom

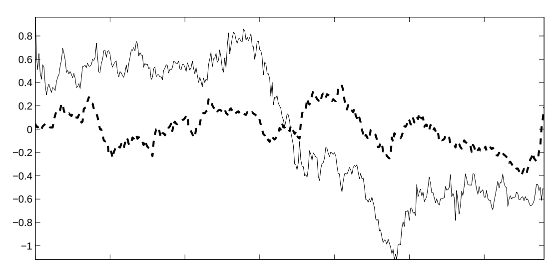


(e) Germany–Japan

(f) Germany–United Kingdom



(g) Japan–United Kingdom



The graphs show the natural logarithm of the real exchange rate for productive capabilities (solid line), and for final goods (dashed line), for the period 1974:12-2008:12.