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Abstract

At a level of individual goods, heterogeneity of marginal transaction costs, proxied by price-to-weight ratios and stowage factors, explains a large part of the variation in thresholds of no-adjustment and conditional half-lives of law of one price deviations. Prices of heavier (more voluminous) goods deviate further before becoming mean-reverting. Moreover, after becoming mean-reverting, prices of heavier goods converge more slowly. Together with measures of pricing power, market size, distance and exchange rate volatility, these factors explain up to 43% of variation in no-adjustment threshold estimates across 52 goods in US-Canada post Bretton Woods monthly CPI data and are robust in a broader 5-country dataset. They open two avenues for the importance of marginal transaction costs in accounting for real exchange rate persistence: through (a) generating persistence in individual real exchange rate components, and (b) accentuating it by the process of aggregation of heterogeneous components ("aggregation bias" of Imbs, et al. 2005).

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Abbreviations: TAR, EQ, BAND, OECD, OT, IMRR, CPI, US, SETAR, RER, AR, ADF, NAFTA, HP, PPP, NTB, DGP, HHI, HTS, P/W, P/V, NAE, CA, UK, NAICS

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1 Introduction

This paper shows that the non-linear behavior of differences in prices of traded products between Canada and US, as well as between five OECD countries, is significantly related to the marginal shipping costs proxied by the physical characteristics of the products. Estimates of thresholds in law of one price deviations for goods are significantly negatively related to price-to-weight ratios and price-to-volume ratios of the same products. Size of the market is also important in explaining threshold heterogeneity: goods with smaller market shares tend to have wider thresholds. Together with the standard explanatory variables[1], these factors explain up to 43% of the variation in threshold estimates. Furthermore, estimates of half-lives of convergence outside of the thresholds are also significantly negatively related to price-to-weight ratios and stowage factors. Not only do price differences of goods goods that are relatively more heavier or voluminous deviate further before becoming mean-reverting, price differences also persist longer outside of the thresholds.

These results suggest the existence of two channels through which marginal shipping costs generate persistence in price deviations of traded goods: directly through "iceberg costs" and indirectly by affecting optimal decisions about the mode of transport. Due to the heterogeneity of marginal shipping costs for traded goods, the two effects can be respectively detected in the heterogeneous thresholds of price deviations as well as in the heterogeneous conditional half-lives. Consequently, detailed modeling of marginal shipping costs is an empirically important avenue for explaining persistence and volatility of price deviations[2].

The empirical framework in this paper is based on the role that transaction costs play in impeding arbitrage. Many theories of international price deviations rely on the existence of sticky prices in an environment with real rigidities. Such theories explicitly assume limits to arbitrage, implying very large transaction costs. In the extreme case, markets in such models are segmented in the presence of local currency pricing by the firms. Households in such models cannot arbitrage away price differences (e.g., Betts and Devereux, 2000). Trade and open macro models often link differences in prices to transportation frictions by assuming that a form of shipping costs is added to the price of the product at the point of origin (or, equivalently, that a fraction of the product's value disappears in the course of transport). Even with market segmentation and pricing to market these theories frequently include a condition $p_{it} = p^*_{it}/(1-\tau)$ where p_{it} is a c.i.f. price of good i at time t in home country (measured at factory gates), p^* is price of the same good abroad and

τ is an iceberg shipping cost (Obstfeld & Rogoff, 2000; Novy, 2006). The above condition is observationally equivalent to arbitrage condition at the level of factory gate prices.

Hecksher (1916) showed the importance of arbitrage for sustainability of price deviations in his calculation of the "commodity points"[3]. In a modern application of that idea, Obstfeld and Taylor (1997, OT hereafter) found that such commodity points were visible in the non-linearity of deviations in sectoral law of one price deviations when estimated by threshold-autoregressive (TAR) models. Their estimates of non-linear threshold are positively related to distance and exchange rate volatility, both measures of transaction costs. Zussmann (2002) finds that tariffs also determine the width of the no-arbitrage band. Imbs et al. (2003, IMRR hereafter) confirm these results and show existence of a similar relationship between transaction costs and conditional half-lives of deviations in prices outside the thresholds. All studies find heterogeneity across sectors in threshold estimates or estimates of conditional half-lives.

This paper shows that no-arbitrage thresholds vary in proportion to the "relative value" of goods, i.e., their price-to-weight or price-to-volume ratios. This is because, at the level of individual goods, physical characteristics of products influence their marginal shipping costs[4]. Ceteris paribus, trade frictions create a smaller ad-valorem wedge for goods that are lighter or less voluminous relative to their price (high-valued products). Conversely, goods with larger volume or weight relative to their price sustain larger deviations before the price difference justifies a shipment[5].

The remainder of the paper is structured as follows: section 2 outlines the idea, section 3 discusses the data, section 4 presents the results and section 5 concludes.

2 Arbitrage

Many open macro (Novy, 2006) and trade (Hummels and Skiba, 2004) models imply that shipping costs and trade barriers lead to differences in prices of goods, at least at the dock level. Such condition is commonly expressed as $SP_{j,g} = P_{i,g} + A_{i,j,g}$ where $P_{i,g}$ is the local currency price of good g in country i, S the nominal exchange rate between i and j and $A_{i,j,g}$ the marginal transaction cost. $A_{i,j,g}$ is usually modeled as a constant consisting of a marginal transport cost[6] and marginal trade barrier (tariffs, etc.): $A_{i,j,g} = t + B$. It can be interpreted as the minimum price difference that makes arbitrage trade profitable between i and j. In an environment with perfectly competitive transport sector using constant returns to scale technology and where sellers of goods have no pricing power, price differences in excess of marginal transaction costs are arbitraged away:

$$-A_{i,j,g} \leq SP_{j,g} - P_{i,g} \leq A_{i,j,g} \quad (1)$$

There are environments in which price differences can exceed marginal transaction costs, e.g., pricing power on the side of sellers, market segmentation, or non-constant returns to scale in transportation sector. Nevertheless, marginal transaction costs in any environment split the price-difference space into two regions: a region of no-arbitrage outlined by (1) and a region with some level of arbitrage where (1) does not hold. This implies a non-linearity in the behavior of the observed price differences: a random walk process in the first region and mean reversion in the second region[7].

It is well known that neither the marginal transport costs nor the tariff barriers are constant across goods and locations. Consequently, the random-walk and mean-reverting regions vary systematically – an implication explored before using threshold-autoregressive models. OT, IMRR and Zussman (2002) use distance, exchange rate volatility[8], tariffs and non-tariff trade barriers as measures of transaction costs to identify sources of variation in threshold estimates for bilateral real exchange rates.

At the level of an individual good, transport costs also depend on good-specific physical characteristics. Hummels (2001, 2003) estimates the dependance of freight costs on physical weight of the goods across four modes of transport (air, ocean, truck and rail) using US Census data and Transborder Surface Trade Database. In his regressions with up to half a million data points, weight-to-price ratios are highly positively significant in explaining the freight rates - more so than the distance of the shipment. To illustrate the implication of this heterogeneity for non-linearity of price-differences, let the total transport costs follow a flexible Cobb-Douglas form. Specifically, let the transport cost depend positively on the weight of a shipment $w_g q_g$, distance between locations d_{ij}, value of the shipment $P_{ig}q_g$ (insurance costs) and negatively on the total trade volume M_{ij} between two locations[9]: $T_{ijg} = (w_g q_g)^{\alpha_1} d_{ij}^{\alpha_2} (P_{ig} q_g)^{\alpha_3} M_{ij}^{\alpha_4}$. $\alpha_k \in (0,1)$ $k = 1, ..., 3$ and $\alpha_4 \in (-1, 0)$[10]. Condition (1) can then be expressed as a condition for good-specific real exchange rate with predictions about the determinants of the no-arbitrage bounds

$$1 - \left(\frac{t_{ijg}}{P_{ig}} + \frac{B_{ijg}}{P_{ig}}\right) \leq \frac{SP_{jg}}{P_{ig}} \leq 1 + \left(\frac{t_{ijg}}{P_{ig}} + \frac{B_{ijg}}{P_{ig}}\right) \tag{2}$$

where $t_{ijg} = \alpha_1 q_g^{\alpha_1 + \alpha_3 - 1} w_g^{\alpha_1} d_{ij}^{\alpha_2} P_{ig}^{\alpha_3} M_{ij}^{\alpha_4}$ is the marginal transport cost. The assumptions on αs imply that bounds of inequality (2) are increasing in the physical characteristic of the good w_g and decreasing in its price P_{ig} as well as the aggregate trade volume M_{ij}. Heterogeneity of marginal transaction costs implies that the non-linearity in price differences varies across goods: heavier, more distant products, or products traded between locations that see little mutual trade should all have wider thresholds. Heterogeneity in thresholds of sectoral real exchange rate found by OT and IMRR is then a result of aggregation in good-specific non-linearities driven by heterogeneous marginal transaction costs at the level of individual goods.

3 Data

Disaggregated consumer price index data is used to measure price deviations. This limits the type of questions the study can address. Although the data does not contain information about the absolute size of price differences[11], information about the dynamic properties of price levels is fully preserved.

3.1 Price index dataset

The price index dataset contains disaggregated seasonally adjusted CPI indexes of 66 groups of goods and services in the United States and Canada between 1970:1 and 2006:05 (some series start after 1970) and the nominal exchange rate[12]. The countries are chosen because of the length and depth of data at a level of disaggregation that allows estimation of physical characteristics of products. Data for matching categories was obtained from Bureau of Labor Statistics and Statistics Canada, respectively. 52 of the series represent goods and 14 services[13], covering 73.5% of the CPI overall (goods cover 24.1% and services 46.7% of the CPI, respectively[14]). Using the taxonomy of Lebow and Rudd (2001), 77% of durable goods, 70% of nondurable goods and 39% of services are included in the data. To assess robustness, and to facilitate comparison of the results with literature, a second dataset from Eurostat adds disaggregated CPI data for 36 product categories for France, Germany and the UK from 1996:1 to 2007:5. Although the second dataset covers fewer product categories over shorter time, it allows the control for standard determinants of thresholds, e.g., distance and exchange rate volatility.

3.2 Physical weights dataset

The dataset of physical weights and individual prices for each good (or group) is constructed using the following data-collection procedure. When available, weights are obtained from statistical agencies or government bodies. Otherwise, manufacturers' associations are searched for average weights of particular products or product groups. In a minority of cases when neither of the approaches works, weights are estimated as an average of the market's large manufacturer's product range (e.g., for watches, an average weight is set equal to a current average weight of a Timex watch). Average prices are obtained in a similar manner[15]. Weight (and price) data of groups of products (e.g., women's apparel) are computed as weighted averages of weights (and prices) of the components using expenditure shares from US urban average CPI in December 2001 as weights. The composition of all groups, data sources, as well as price and weight estimates are documented in table 1 in the Appendix.

3.3 Volume dataset

The dataset of physical volumes is calculated indirectly using data on stowage factors from the German Transportation Information Service database[16] and weights of goods. Stowage ratios for products that are not included in the German database are found using other data sources. Table 2 in the Appendix documents all data sources.

4 Empirical framework and results

The first part of this section estimates threshold-autoregressive (TAR) models on good-specific real exchange rate data. The second part assesses the extent to which heterogeneity in marginal transaction costs explains heterogeneity of threshold estimates and conditional half-lives. The discrete break in good-specific real exchange rates implied by equation (2) guides the choice of a discrete self-exciting TAR models[17]. The nature of the break driven by heterogeneity of t_{ijg} across goods can be captured well by a highly disaggregated data on hand[18]. Logarithm of good-specific real exchange rate z_t^g is used as the object of first-stage estimation: $z_t^g = p_t^g - p_t^{g*} + s_t$, where t is a time index and g is a good (service) index, p and p^* denote logarithm price indexes in US and Canada, respectively, and s_t is the logarithm of the nominal exchange rate.

4.1 Specification, estimation and testing

Specification of a TAR model requires selection of a number of thresholds, number of autoregressive lags p and of an optimal delay parameter d_p. I assume two thresholds[19] for each good. Since there is no a-priori reason for t_{ijg} to have different effects in appreciation and depreciation, I also assume symmetry: $\gamma_1^g = -\gamma_2^g \equiv \gamma^g \; \forall g$. The main model is a Band-TAR(2,p,d) specified as:

$$\Delta z_t^g = \begin{cases} \bar{\beta}^{g,out}(\bar{z}_t^g - \gamma^g) + e_t^{out} & \text{if } z_{t-d_p}^g > \gamma^g \\ \bar{\beta}^{g,in}\bar{z}_t^g + e_t^{in} & \text{if } \gamma^g \geq z_{t-d_p}^g \geq -\gamma^g \\ \bar{\beta}^{g,out}(\bar{z}_t^g + \gamma^g) + e_t^{out} & \text{if } -\gamma^g > z_{t-d_p}^g \end{cases} \tag{3}$$

where $\bar{z}_t$ is the vector of the appropriate lagged values of z_t, e_t^{out} ~N$(0, \sigma_B^{out2})$ and e_t^{in} ~N$(0, \sigma_B^{in2})$. For robustness, Equilibrium-TAR (Eq-TAR) model is also estimated:

$$\Delta z_t^g = \begin{cases} \bar{\beta}^{g,out} \bar{z}_t^g + e_t^{out} & \text{if } z_{t-d_p}^g > \gamma^g \\ \bar{\beta}^{g,in} \bar{z}_t^g + e_t^{in} & \text{if } \gamma^g \geq z_{t-d_p}^g \geq -\gamma^g \\ \bar{\beta}^{g,out} \bar{z}_t^g + e_t^{out} & \text{if } -\gamma^g > z_{t-d_p}^g \end{cases} \tag{4}$$

where e_t^{out} ~N$(0, \sigma_E^{out2})$ and e_t^{in} ~N$(0, \sigma_E^{in2})$. Because identification of the thresholds relies on (2), both specifications assume no mean reversion of price difference between the thresholds (a restriction of $\bar{\beta}^{g,in} = 0$). This assumption is valid and innocuous: In the data, 70% of $\bar{\beta}^{g,in}$ estimates are not significantly different from zero[20], and a relaxation of this restriction by estimating $\bar{\beta}^{g,in}$ has a minimal effect on the results (regression 7 in table 5). The two above specifications differ in their assumptions on mean-reversion of z_g outside thresholds. Band-TAR assumes that price differences converge back to the no-arbitrage threshold, in line with equation (2). Eq-TAR assumes convergence back to the middle of the no-arbitrage band (mean). Hence, Band specification produces faster conditional convergence speeds. Results from both specifications are very similar and only Band-TAR results are reported.

Specification and estimation of each TAR(2,p,d) proceeds in three steps[21]. First, the appropriate lag-structure p of the linear model is selected from up to 12 monthly lags using AIC and SBIC. Second, given the lag structure p, optimal delay parameter $d_p (d_p \in \{1, ..., 12\})$ is selected by Tsay's (1989) procedure: $\hat{F}(p, d_p) = \max_{\nu \in S} \hat{F}(p, \nu)$ where $\hat{F}$ is the F-statistic obtained during recursive least squares regression using arranged case data. By construction, optimal d_p gives the most significant result in testing for non-linearity. Given optimal p and d_p, parametric maximum likelihood estimation procedure according to OT (who follow Fanizza, 1990; Balke and Fomby, 1997 and Prakash, 1996) obtains $\hat{\gamma}$ and $\hat{\beta}$. The procedure is a best-fit grid search for a threshold parameter γ that maximizes the log-likelihood ratio $LLR = 2(L_a - L_0)$ where L_a and L_0 are the log likelihoods of the TAR(2,p,d) and AR(p) estimates, respectively[22]. Estimates of $\hat{\beta}$ are used to compute conditional half-life of convergence using impulse response functions.

Two tests are used to assess the non-linear TAR against the linear alternative: likelihood ratio test and Tsay's general nonparametric F-test. Likelihood ratio test uses LLR statistic obtained during the grid-search, with Monte Carlo simulation of 5000 draws used to obtain the p-values of the statistic[23]. Tsay's general nonparametric F-test uses the minimal p-value of two F-statistics obtained from recursive least squares regressions using arranged case data: one from an arranged regression using ascending ordering of the case data, another with descending orderings of the case data[24].

4.2 Non-linearities

A vast majority of the series can not reject the H_0 of unit root by either ADF or Philips-Perron tests (columns 3 and 4 in table 3). Unit roots appear to be rejected for the more valuable series with the notable exception of foods. Tsay's test for threshold non-linearity[25] rejects linearity in favor of TAR for 57 out of 66 series specification (column 2 in table 3). We can conclude that, for most series, threshold autoregressive models offer a more suitable characterization of price differences than linear models[26]. The non-linearities are distributed fairly evenly across all goods and services.

Space limitations require reporting of only general results. As is well known, model misspecification leads to over-estimation of half-lives (see, i.a., OT). This is highlighted in the reduction of an average half-life for all series with AR point estimates inside the unit circle from 126 months under AR(1) specification to 63 months under TAR(2,p,d) (table 4). Slightly larger reductions are observed for goods (drop from 112 to 52 months on average) than services (drop from 202 to 123 months). Services and medical products have the longest AR half-lives. Price differences for cars, car parts, clothing and footwear are quickest in converging to mean. Vice goods, medical and chemical products, and to a smaller degree cars, car parts, clothing and footwear all see a marginal increases in half-life while high-tech goods drop significantly. General findings also confirm – at a greater level of disaggregation than IMRR – a positive correlation between AR half-life and the threshold width, as well as between AR half-life and the reduction of half-life from AR to TAR specification (see figure 1). Slowly-reverting goods tend to have larger thresholds and larger drops in conditional persistence.

4.3 Determinants of thresholds

Arbitrage condition (2) predicts a relationship between the estimates of thresholds $\hat{\gamma}^g$ in equations (3) and (4) and good-specific determinants of marginal transaction costs. This guides the empirical specification:

$$\hat{\gamma}^g = \beta_0 + \sum_{i=1}^{k} \beta_i y_i^g + \epsilon^g \tag{5}$$

where y_g^i is a vector of good-specific determinants of marginal transaction costs. For all regressions, y_g^i includes measures of physical characteristics of goods (price-to-weight, or price-to-volume ratios), trade barriers (tariffs and non-tariff barriers), price-setting power and market structure (market size proxy and industry concentration), a macroeconomic variable of sectoral inflation and a refrigeration dummy variable[27]. In regressions with 5 countries' data, y_g^i also includes distance and bilateral nominal exchange rate volatility[28], both standard determinants of transaction costs (see IMRR). Tariffs are measured as an average tariff rate for the product category in 1989, date approximately half way through the gradual tariff-reduction process under NAFTA[29]. Non-tariff barriers are from the World Bank's Trade, Production and Protection database[30]. With increasing returns to scale in production (e.g., in the presence of fixed costs), market size matters for profits. If larger markets are more attractive, they should be associated with smaller price-setting power. Therefore, CPI expenditure shares across goods are included as a measure of the price-setting power. Market structure also directly influences price-setting power of firms, guiding the choice of Herfindahl-Herschmann index from 1997 US Economic Census as a measure of pricing power due to individual market's structure[31]. Sectoral inflation rate refers to the average absolute annual CPI inflation rate in the relevant sector[32] and is used as a measure of price rigidity.

Price-to-weight ratios are highly significant in explaining thresholds (regressions 1 and 2 in table 5). Other things constant, heavier goods (relative to their value), due to their larger marginal transport costs, have wider thresholds of no-arbitrage. A ten-fold increase in the price-to-weight ratio increases the threshold by 0.37 percentage points (i.e., widens the no-arbitrage band by 0.74 percentage points). The elasticity of threshold width with respect to a good's price-to-weight ratio is -0.54 (regression 11), highly significant, and alone explains 35% of variation in log-thresholds across 47 product categories.

Measures of price-setting power are also important in explaining thresholds. Expenditure share is significantly negative in some of the regressions. A hypothesis consistent with this finding is that of market size determining price-setting power, possibly because of a lower degree of monopoly power in larger markets. Tariffs and Herfindahl-Hirschman index are not significantly different from zero[33]. Non-tariff barriers, while insignificant in most regressions, enter significantly with a negative sign in 4 regressions. This result is somewhat counter-intuitive as it suggests that sectors with larger non-tariff barriers exhibit lower no-arbitrage bands. OT and IMRR report similar results, with the former finding food sector particularly significant.

The role of price-to-weight ratios in determining no-arbitrage bands remains highly significant after controlling for the standard transaction cost variables such as distance and exchange rate volatility in a five-country dataset (table 6). A ten-fold increase in P/W lowers no-arbitrage threshold by 0.15 percentage points. As expected, the effects of distance are also highly significant and positive, however only half the size of the effects estimated by IMRR[34]. This is likely due to the omission of an important variable - physical characteristics of goods - from their regressions. Nominal exchange rate volatility has positive but insignificant effect on thresholds of a similar magnitude to the estimates in the literature. Sectoral inflation is significantly positively related to the size of the thresholds. If we interpret average inflation as an inverse measure of price stickiness, sectors with more sticky prices tend to have narrower no-arbitrage thresholds – a counter-intuitive result. A closer scrutiny suggests that this result is driven by a high average inflation rates in gas and information processing sectors as a result of a persistent decline in prices of computer equipment and an increase in prices of petroleum products, respectively. This complicates a structural interpretation of the effects of sectoral inflation. Finally, tariffs and non-tariff barriers are not significant, in line with the literature.

4.3.1 Robustness of threshold regressions

Robustness of these results is verified using six methods: (a) use of price-to-volume as an alternative measure of physical characteristics of goods, (b) exclusion of goods with limited tradability, (c) Tobit estimations allowing for linearity control, (d) a re-estimation of TAR models after restricting thresholds to reflect the decline in transport costs (only for US-Canada dataset), (e) a re-estimation of threshold regressions using HP-filtered data and (f) by relaxing the restriction that $\bar{\beta}^{g,in} = 0$ in TAR(2,p,d) estimation.

For some modes of shipments (primarily container) volume as well as weight are important determinants of shipping costs. Price-to-volume ratios are also significantly negatively related to the thresholds estimates, with an elasticity of -0.36 significant at 1% (regression 12 in table 5). Second, regressions are re-estimated after excluding goods that are known to have limited tradability. Regression 13 in table 5 excludes liquor, beer and wine as well as and gasoline and natural gas[35]. As expected, price-to-weight and price-to-volume ratios are more significant than in the original specification. Third, to control for linearity of the series, equation (5) is re-estimated with Tobit estimator which sets $\gamma^g = 0$ for series which can not reject linearity (regressions 5 and 6 in table 5 and regressions 3 and 4 in table 6. In addition, OLS regressions are re-estimated with only series for which linearity is rejected (regression 3 in table 5 and regression 2 in table 6). The original results carry through in all cases, with physical characteristics remaining and expenditure weight becoming significant.

Fourth, BAND-TAR(2,p,d) model is re-estimated under the constraint that marginal transport costs have declined throughout the sample period[36]. Novy (2006) estimates that Canada-US transport costs dropped by 39% between 1960 and 2002. This overall decline is pro-rated to the sample length and thresholds for each product are forced to decline at that rate. Regressions 8-10 in table 5 show that the results remain highly significant, explaining up to 40% of variation in thresholds. In addition to the importance of price-to-weight ratios, Herfindahl-Hirshman index (and expenditure shares) are individually significantly positively (negatively) related to the width of the thresholds, in support of the hypothesis that lack of competition increases price-setting power of firms. The expenditure share is also significant in the Tobit estimations. The increase in the size of the price-to-weight and expenditure share coefficients in all specifications is understandable when thresholds estimates take into account the empirically documented changes in transport costs.

Most of the bilateral nominal exchange rates in the 5-country sample have a secular hump-shaped trend which may affect threshold estimates (figure 2). As in OT, an HP-filtered dataset is used to re-estimate thresholds and their relationship with physical characteristics of goods and other usual determinants of marginal transaction costs. Regressions 5 and 6 in table 6 show that price-to-weight ratios remain marginally significant in Tobit regression, in addition to all usual determinants of marginal transaction costs.

Finally, the restriction that AR coefficient $\bar{\beta}^{g,in} = 0$ inside the TAR(2,p,d). Regression 7 in table 5 reports the results which are consistent with the basic findings.

4.4 Determinants of conditional persistence

The second part of the analysis investigates the dependance of conditional persistence of prices on marginal transaction costs. The estimation is based on

$$\log(\hat{hl^g}) = \delta_0 + \sum_{i=1}^{k} \delta_i y_i^g + \nu^g \tag{6}$$

where $\hat{hl^g}$ is the conditional half-life estimated by impulse response functions using TAR estimates from (3) and y_i is a vector of explanatory variables[37]. Results from US-Canadian and five-country datasets are reported in tables 7 and 8, respectively.

Persistence of price differences outside of the thresholds co-varies negatively with price-to-weight ratios, refrigeration dummy as well as sectoral inflation rates at 1% significance level in all regressions. The basic estimation explains 38% of the variance. Price differences for goods with larger marginal transaction costs (relatively heavier goods) take longer to converge to the no-adjustment bound (the elasticity is -0.23 and significant at 1%). This result may be caused by the importance of marginal transaction costs in the decision on the *mode* of transport. Hummels

(2001b) estimates that, in bilateral US trade data, each day saved shipping is worth 0.8 percentage ad-valorem points for manufactured products. Larger average price differences for goods with bigger marginal transport costs then justify use of slower mode of transport[38]. The other variables confirm findings of OT and IMRR. Tariffs and non-tariff barriers are insignificant in all specifications. Sectoral inflation is significant with a negative sign, suggesting that sectors with a higher degree of price stickiness have longer half-lives.

The results in the five-country dataset confirm the importance of physical characteristics for conditional half lives using a metric of stowage factors (price-to-weight ratios are significant in specification 5 of table 8). This suggests that goods which are more voluminous relative to their *weight* converge more slowly to the no-arbitrage bound (regressions 2 and 4 of table 8). Such preference for a different specification may be caused by the trans-Atlantic nature of the five-country dataset as volume is more important in sea than in land transport[39]. The result highlights the need to account for the mode of shipment. Exchange rate volatility and distance are significantly positively related to half-lives, as in IMRR. Refrigeration dummy remains highly significant, suggesting that goods requiring refrigeration are transported more quickly, this speeding the price convergence process. Sectoral inflation significantly positively affects conditional half-life in the five-country dataset – a puzzling result with an opposite sign to previous regression[40]. Contrary to the expectations, industries with more sticky prices (lower inflation) tend to experience quicker adjustment to the no-arbitrage band. However, this result is not significant after removing two outlier industries (gas and information processing equipment) with respective sectoral inflation rates 10 and 5 times the median of all industries. It is likely that sectoral inflation combines sectoral differences in technology adoption and demand growth and therefore is a very noisy measure of sectoral price stickiness[41]. This effect disappears when using detrended price data (regression 5 in table 8).

4.4.1 Robustness of persistence regressions

The above results are robust to various specification changes. Neither the exclusion of goods with limited tradability (energies and alcoholic beverages in regressions 2 and 3 of table 7), nor the exclusion of goods that do not reject linearity (regression 4 in table 7 and regressions 3 and 4 in table 8) affect the estimated relationship. Re-estimation of conditional half-lives using HP-detrended data reveals a marginally significant negative relationship between price-to-weight ratios and half-lives. In addition, expenditure shares lower conditional half-lives, possibly also because of the the importance of market size for competition. Distance variable remains a significant determinant of half-lives but nominal exchange rate volatility is not.

5 Conclusion

Physical characteristics of goods, through their importance in the marginal transaction costs, explain a large part of the threshold non-linearity and conditional persistence of law-of-one-price deviations. Visible at a sufficiently detailed level of disaggregation, this mechanism creates heterogeneity at higher levels of aggregation such as the sectoral real exchange rates. Using two post-Bretton Woods monthly datasets, a detailed US-Canadian series covering 52 products and product groups and a less detailed five-country series spanning 36 product groups, it is found that heavier goods (relative to their price) see their price differences diverge further before becoming mean reverting (transport costs are higher for those goods because they are more difficult to move). Furthermore, after becoming mean reverting, price differences for heavier or more voluminous goods converge more slowly, possibly due to choice of slower mode of transport for goods with larger average price differences. Both mechanisms increase the unconditional persistence of the price differences of products with higher marginal transaction costs.

This account of the determinants of heterogeneity in the behavior of price differences also sheds light on the puzzling persistence of real exchange rates. Imbs, et al. (2005b) show how the peculiar nature of aggregating heterogeneous real exchange rate components accentuates the persistence at the level of the aggregate real exchange rate. There is a discussion about the extent to which such ”aggregation bias” explains PPP puzzle (see also Chen and Engel (2004)). This study shows that a source of the heterogeneity in real exchange rate components, and therefore of aggregation bias, lies in the heterogeneity of marginal transaction costs across goods caused by the importance of physical characteristics in shipment. The effects of these, as well as the effects of the composition of the trade basket at a micro level, warrant further study. Theoretical models that take heterogeneity of marginal transaction costs into account may stand a better chance of explaining the puzzling persistence in aggregate real exchange rates.

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Notes

[1]Sectoral inflation, distance and exchange rate volatility.

[2]To the extent that this heterogeneity is important for our understanding of the persistence in the deviations of real exchange rates (see the ”aggregation bias” discussion: Imbs et al., 2004 and 2005; Chen and Engel, 2004), this result contributes to our understanding of the PPP puzzle by specifying the sources of non-linear heterogeneity.

[3]More recently, Engel and Rogers (1996) re-ignited the discussion about the characteristics and determinants of law of one price deviations.

[4]The fact that physical characteristics (weight and volume) of goods determine freight rates has been documented by Hummels 1999 and 2001).

[5]For example, a 10% difference in price of a PC between downtown and a suburb of a city may offset the transport cost. However, a 10% price difference of a less valuable good - e.g., an equally-sized bag of potatoes - may be insufficient to justify the transport from an equidistant location.

[6]Transport costs also matter through their importance in distribution. Burstein et al. (2003) find that distribution margins can account for up to 60% of price differences between US and some latin-American countries.

[7]Such non-linearity also exists in the presence of other reasons for trade.

[8]Exchange rate volatility is thought to affect no-arbitrage bands through the effects of uncertainty in a fixed-cost environment.

[9]Bigger trade routes justify use of larger vessels, longer trains, etc.

[10]Because doubling of distance, shipment size, etc., does not require doubling of resources used in transportation (decreasing returns to factor accumulation due to efficiency gains – see Hummels, 2001)

[11]See Crucini, Telmer and Zachariadis (2005) for a price level analysis that documents widespread law of one price violations (hence mean does not equal parity) across the EU.

[12]Data is carefully checked and cleaned for outliers which can affect the estimates of measures

of non-linearity.

[13]Services are included only as an indirect check of data consistency. Because of their poor tradability, wider threshold estimates are expected for services than for goods.

[14]Source: CPI all urban consumers, Bureau of Labor Statistics, December 2001. Some of the groups are a subset of other groups - all such double accounts are excluded in this measure.

[15]A search of US data sources preceding a search of Canadian data sources. Price level necessary to construct a price-to-weight ratios across goods corresponds to an average USD price in year 2000.

[16]A website run by the German Insurance Association:
`http://www.tis-gdv.de/tis_e/ware/inhalt.html`. A stowage factor of a cargo is the ratio of weight to stowage space (the unit is ton/m^3) required under normal conditions, including all packaging. Because stowage factors for goods can vary depending on packaging, water contents, and compression, an average of all quoted stowage factors is used to calculate the volume of a good.

[17]Self-exciting threshold autoregressive (SETAR) models can be thought of as a combination of several (typically two) regimes which differ in the degree of stationarity they impose on the series. The decision on which regime shall the variable observe depends on a position of a control variable - in ”self-exciting” models this is just a lagged value of the examined series.

[18]Aggregation would make smooth threshold autoregressive models more appropriate. In a smooth threshold autoregressive model reversion occurs for any deviation and its strength rises in the size of the deviation (for references see, i.a., Tong 1990; Granger and Teräsvirta 1993).

[19]One threshold following sufficient appreciation, another one after depreciation.

[20]Confidence intervals for $\bar{\beta}^{g,in}$ are constructed using the method in Hansen (1997).

[21]See Granger and Teräsvirta (1993), Teräsvirta(1994), Tsay (1986) and Tsay(1989).

[22]Threshold estimates $\hat{\gamma}$s do not appear to be very sensitive to the choice of the grid boundaries.

[23]The statistic does not follow the asymptotic χ^2 distribution in a non-linear model because the threshold parameter γ is not identified under H_0 of linearity.

[24]See Tsay (1986), OT, Ertel and Fowlkes (1976) or the author's website for details.

[25]With two symmetric thresholds, Tsay's test (Tsay, 1986) is more appropriate than Hansen's (1997) single-threshold non-linearity test.

[26]The precision with which we can conclude non-linearity or non-stationarity depends on the length and breadth of the sample as well as on whether the test statistic controls for the serial correlation of the error terms. O'Connel (1998) shows how a failure to account for serial correlation leads to serious size distortions. Papell (1997) shows that various panel datasets provide stronger rejection of the unit root hypothesis than a similar time-series analyses. While panels improve the power of unit root tests, they suffer from series of other problems (see, e.g., Lyhagen, 2000; Bornhorst, 2003; Banerjee et al., 2001). In addition, power of unit root tests drops further when the underlying DGP is not linear.

[27]Refrigeration dummy = 1 for goods requiring refrigeration in transport. I thank an anonymous referee for suggesting to include this variable in threshold regressions as well, although with limited success.

[28]Greater circle distance in km between capital cities is used as a measure of country distance and standard deviation of bilateral nominal exchange rate as a measure of exchange rate volatility.

[29]For groups of goods, a weighted average tariff computed using CPI weights of constituent products is computed. Tariff data comes from Tariff Database collected by John Romalis (see Feenstra, Romalis and Schott (2002)

[30]See `http://go.worldbank.org/EQW3W5UTP0`. The variable used is Weighted ad-valorem equivalent of NTB.

[31]Value-added based index is used. Data is available at

`http://www.census.gov/epcd/www/concentration.html`.

[32]I thank an anonymous referee for this suggestion.

[33]OT and IMRR also report insignificance of tariffs.

[34]Note that IMRR measure distance in thousands of km.

[35]Alcohol trade is restricted at all levels, while gasoline and natural gas requires sophisticated

and expensive distribution networks (e.g., pipelines), making physical characteristics irrelevant as measures of marginal transport costs.

[36]Due to lack of information on the declines of transportation costs between various country pairs, this exercise is only performed for the US-Canada dataset.

[37]Specification (6) is taken from Imbs et al., (2003)

[38]It could also be a consequence of partial substitution into cheaper but slower transport modes for goods that have larger marginal transport costs (here identified by their physical characteristics).

[39]Consequently, weight is more important in the US-Canada dataset while volume plays a bigger role in the ”Atlantic” 5-country dataset.

[40]IMRR find a similar - although insignificant - relationship.

[41]Part of the heterogeneity in sectoral inflation rates can be contributed to differences in sectoral rates of technological growth – especially in the IT sector – and growth in world demand – in both IT and oil sectors – rather than to structural differences in the way prices are set across industries.

Appendix

item	unit	price	curr.	weight (kg)	p/w (USD/kg)	note
Apples	kg	2.57	CND	1	1.7	05/00-05/01 average, Statcan Table 326-0012
Audio equipment	stereo unit	150	USD	6	25	www.jandr.com (the largest retailer in US), includes packaging
Beef	ground, 1kg	4.63	CND	1	3.06	05/00-05/01 average, Statcan Table 326-0012
Beer	six pack	5.40	USD	2.30	2.35	See Grossmann & Markowitz (1999)
Car purchase	car	24,923	USD	1326.13	18.79	1996 avg. extrapolated to 2000, American Automobile Manufacturers' Association 1996
Car parts	tire	100	USD	10	10	
Cheese	kg	8.69	USD	1	8.69	Avg. of American processed cheese (Series APU0000710211) and Cheddar cheese (Series APU0000710212) BLS, 2001 average monthly
Clothes						
Clothes (men)	basket#	USD			50.52	U.S. Department of Commerce, 2000
Clothes (women)	basket#	USD			52.93	U.S. Department of Commerce, 2000
Coffee	roast, 300g	3.27	CND	0.3	7.20	05/00-05/01 average, Statcan Table 326-0012
Educ. books & supplies						
Eggs	dozen	1.91	CND	0.73	1.74	05/00-05/01 average, Statcan Table 326-0012 weight: a 30-dozen egg container weighs 47lb.
Electricity	500 kWh	48.55	USD	–	–	BLS, average 2001 price (Series APU000072621)
Fats and oils	basket*	1.81	USD	0.598	3.68	StatCan, Avg price in Calgary in Nov 2001 for Salad dressing, avg. price in NYC, Feb 2001
Fish and seafood	basket+	2.85	USD	1	2.85	Fish processing industry data, wholesale prices.
Flour	2.5kg	3.37	CND	2.50	0.89	05/00-05/01 average, Statcan Table 326-0012
Footwear						
Footwear (men)	pair, avg of casual and athletic	46.50	USD	0.73	63.70	
Footwear (women)	pair, athletic	43.88	USD	0.56	81.00	
Fuel oil	liter	0.34	USD	0.86	0.39	Avg price, BLS 2001, Series APU000072511
Furniture	bed	200	CND	46.7	4.3	IKEA
Gas	1000 ft^3	7.45	USD	18.16	0.41	Avg price for year 2000, Energy Information Administration, Natural Gas Monthly, Jan 2002
Gasoline	liter	0.38	USD	0.70	0.54	Avg. price, BLS, 2001, Series APU000074714
House chemicals	75oz pack of laundry deterg.	2.30	USD	2.13	1.16	1997 NYC price extrapolated into 2001
Jewelry	–					
Laundry appliances	washer	887	USD	158.9	5.58	2002 avg. price for Maytag
Liquor	750ml whiskey	11.74	USD	0.75	15.65	BLS avg. price for 1986, adjusted by CPI inflation (series APU0000720211)
Medical care products						
Non-prescription med.						
Pants	pair, jeans, avg.	50.18	USD	1.36	36.86	Parsley & Wei (2001) and US Dep. of Commerce, avg. price 01/00-07/00
PC	unit	1000	USD	20	50	Dell.com average price in 2002.
Personal care products	a basket[1]	12.58	CND	8.31	2.77	05/00-05/01 average, Statcan Table 326-0012
Photo equipment	–					
Pork	kg, chops	9.29	CND	1	6.14	05/00-05/01 average, Statcan Table 326-0012
Potatoes	4.54kg	3.83	CND	4.54	0.56	05/00-05/01 average, Statcan Table 326-0012
Poultry	kg	4.45	CND	1	2.94	05/00-05/01 average, Statcan Table 326-0012
Prescription medicine	–					
Sport equipment	basket%	99.67	USD	2.10	65.00	http://www.usolympicteam.com/sports2/ih/az equip.html
Sport vehicles	bicycle	225	USD	15	15.00	
Sugar	1lb	0.43	USD	0.45	0.95	BLS avg. price for 2001 (Series APU0000715212)
Tobacco	200 cigs	37.78	CND	0.25	99.80	05/00-05/01 average, Statcan Table 326-0012
Toys	basket	31.33	USD	2.55	13.19	average of 5 age-group categories from Toys'R'Us 2001.
Video equipment	basket**	226.67	USD	8.73	25.96	from J&R website, the largest US retailer, includes packaging.
Watches	piece	50	USD	0.2	250	Timex website avg. price, weight approximated
Wine	liter	5.96	USD	1.3	4.58	BLS avg. price, 2001 (series APU0000720311)
Fresh fruits	basket	19.36	USD	8	2.42	BLS avg. price, 2001
Reading materials	book	30	USD	0.5	60	
Tomatoes	kg	2.90	USD	1	2.9	BLS avg. price, 2001 (series APU0000712311)

#Men's basket: coats, blazers, trousers, suits. Women's basket: coats, dresses, blazers, trousers, suits, and skirts. *Margarine (Canola, 1.36kg), Butter (Parchment, 454g), Shortening (454g), Oil (Canola, 1l), Lard (454g), Peanut butter (500g), and Salad dressing (8oz). Weights equal CPI weights. +Canned fish composition matches the composition of the fish processing industry data. **Canned**: Tuna (48%), Salmon (12%), Clams (8%), Sardines, Shrimp, **Fillets**: Cod (4.7%), Flounder (1.7%), Haddock, Rockfish, Pollock (11%) and Other (11%), **Fresh fish** approximated by 50% tuna and 50% salmon. %Sports basket: ski boots, skis and bindings, tennis racquet, basketball, golf set (11pc), dozen golf balls, hockey stick, hockey skates, inline skates and hockey helmet. **Average of a TV set, a VCR, and a camcorder.

Table 1: Data sources on weights and prices

item	unit	price	stowage factor	volume (m^3)	p/v (USD/m^3)	note
Total RER-CPI						
Apples	kg	2.57	2.622	0.003	647.4	boxes, http://www.tis-gdv.de/tis_e/ware/obst/apfel/apfel.htm
Audio equipment	stereo unit	150	5.495	0.055	2730	http://www.jr.com/JRProductPage.process?Product=3967701
Beef	ground, 1kg	4.63	1	0.001	3057.8	http://www.tis-gdv.de/tis_e/ware/fleisch/gekuehlt/gekuehlt.htm
Beer	six pack	5.40	1.556	0.004	1508.9	http://www.tis-gdv.de/tis_e/ware/lebensmi/bier/bier.htm
Car purchase	car	24,923	8.399	11.138	2237.7	http://www.fordvehicles.com/Cars/focus/features/specdimensions/
Car parts	tire	100	4.041	0.04	2474.6	http://amchouston.home.att.net/stowage factors.htm
Cheese	kg	8.69	1.397	0.001	6222	http://www.tis-gdv.de/tis_e/ware/milchpro/kaese/kaese.htm
Clothes						
Clothes (men)	basket[#]		4.728		10686.4	http://www.tis-gdv.de/tis_e/ware/textil/konfektion/konfektion.htm
Clothes (women)	basket[#]		4.728		11208.1	http://www.tis-gdv.de/tis_e/ware/textil/konfektion/konfektion.htm
Coffee	roast, 300g	3.27	1.961	0.001	3671.3	Rodrigues et. al. (2003)
Educ. books & supplies						
Eggs	dozen	1.91	2.755	0.002	630.7	measurement
Electricity	500 kWh	48.55		–	–	
Fats and oils	basket[*]	1.81	1.25	–	2944	German transportation database source for each component
Fish and seafood	basket[+]	2.85	1.85	–	1537.8	German transportation database source for most components
Flour	2.5kg	3.37	1.33	0.003	669.4	http://amchouston.home.att.net/stowage factors.htm
Footwear						
Footwear (men)	pair, avg of casual and athletic	46.50	21.918	0.016	2906.3	Mens shoe box 14-3/4" x 10-1/8" x 5-5/8"
Footwear (women)	pair, athletic	43.88	28.351	0.014	2857.1	
Fuel oil	liter	0.34	1.163	0.001	338	
Furniture	bed	200	4.73	0.22	909.1	http://www.ikea-usa.com/webapp/wcs/stores/servlet/... ...ProductDisplay?catalogId=10101&storeId=12&productId=32145&... ...langId=-1&parentCats=10103*10144
Gas	1000 ft^3	7.45	1559.298	28.317	0.3	
Gasoline	liter	0.38	1.434	0.001	337	
House chemicals	75oz pack of laundry deterg.	2.30	10.591	0.021	109.5	measurement
Jewelry	–					
Laundry appliances	washer	887	4.506	0.716	1238.8	http://www.maytag.com/products/images/products/dmsearcywash.pdf
Liquor	750ml whiskey	11.74	1.75	0.001	8944.8	http://www.tis-gdv.de/tis_e/ware/genuss/rum/rum.htm
Medical care products						
Non-prescription med.						
Pants	pair, jeans, avg.	50.18	3.57	0005	10328	http://www.tis-gdv.de/tis_e/ware/textil/konfektion/konfektion.htm
PC	unit	1000	25	0.5	2000	http://www.shipit.co.uk/Overseas Removals Companies Volumes.htm
Personal care products	a basket[1]	12.58	8.664	0.024	346.2	measurement of basket items
Photo equipment	–					
Pork	kg, chops	9.29		1	6.14	
Potatoes	4.54kg	3.83	1.7	0.002	3609.1	http://www.tis-gdv.de/tis_e/ware/gemuese/kartoffe/kartoffe.htm
Poultry	kg	4.45	1	0.005	557.1	volume identical to beef
Prescription medicine	–					
Sport equipment	basket[#]	99.67	23.61	0.036	2753.3	various sources for items[#]
Sport vehicles	bicycle	225	17.864	0.268	839.7	http://www.crateworks.com/frameset.html?page=features
Sugar	1lb	0.43	1.354	0.001	699.5	http://www.tis-gdv.de/tis_e/ware/zucker/weiszuck/weiszuck.htm
Tobacco	200 cigs	37.78	0.002	6	13861	http://www.discount-cigarettes-online.biz/templates/faq.php
Toys	basket	31.33	–	0.2	156.7	approximation
Video equipment	basket[*]	226.67	0.044	5	5191.4	http://www.tis-gdv.de/tis_e/ware/maschinen/unterhaltung/unterhaltung.htm
Watches	piece	50	–	0.0012	41667	dimensions: 20x10x5cm, volume calculated directly
Wine	liter	5.96	1.175	0.0015	3973.3	same stowage factor as liquor
Fresh fruits	basket	19.36	2.95	0.024	820.3	German transportation database source for each component
Reading materials	book	30	1.78	0.001	33707.9	http://www.tis-gdv.de/tis_e/ware/papier/zeitung/zeitung.htm
Tomatoes	kg	2.90	2.373	0.002	1221.9	http://www.tis-gdv.de/tis_e/ware/gemuese/tomaten/tomaten.htm

The composition of product groups is identical to Table 1. Additional data sources: [#] Sports basket contains ski boots (http://www.snowshack.com/head-boot-bag.html), skis and bindings (http://www.snowshack.com/salomon-equipe-2pr-skibag.html), tennis racquet, basketball (http://experts.about.com/q/2551/1184149.htm), golf set (11pc, length 44in = 111cm), dozen golf balls (http://www.overstock.com/cgi-bin/d2.cgi?PAGE=PROFRAME&PRODID=676397), hockey stick (http://www.unleash.com/picks/sportinggoods/topsportinggoodshockeysticks.asp), hockey skates (15-in x 9-in x 15-in bag), and inline skates and hockey helmet http://secure1.esportspartners.com/store-redskins/main detail.cfm?nCategoryID=4&nObjGroupID=134&nProductID=56453

Table 2: Data sources on volume

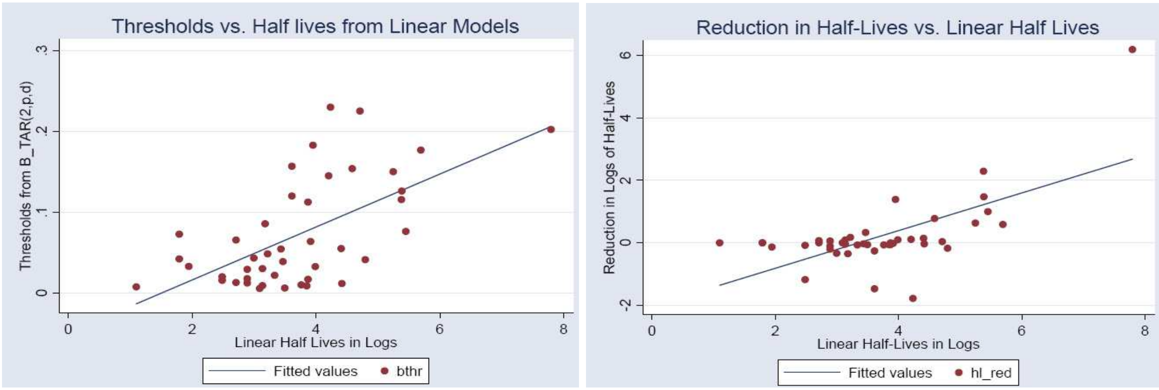

Figure 1: Thresholds and Half Lives

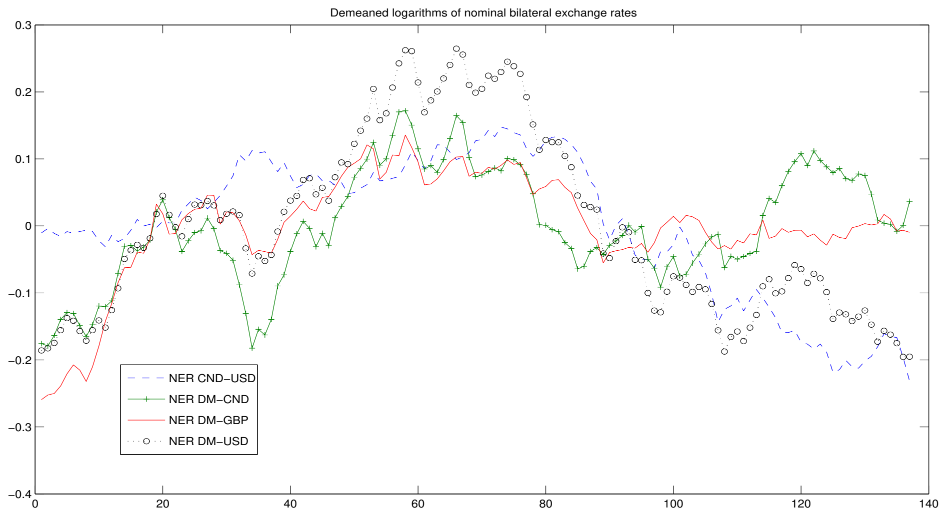

Figure 2: Secular hump-shaped trend in nominal exchange rates

	1	2	3	4	5
	# of obs.	Tsay's non-linear test (p-value)[a]	ADF p-value[b]	Philips-Perron[b]	AR(p) half-life[c]
Airline	437	0.002	0.105	0.000	15
Apples	437	0.000	0.167	0.000	7
Audio equipment	257	0.020	0.558	0.602	79
Beef	425	0.016	0.146	0.066	22
Beer	437	0.131	0.152	0.172	308
Cable TV	262	0.035	0.280	0.291	48
Car	437	0.048	0.010	0.015	74
Car Insurance	437	0.010	0.094	0.071	48
Car Maintenance	333	0.127	0.658	0.643	79
Car Parts	257	0.014	0.019	0.018	69
Cheese	257	0.008	0.720	0.720	95
Child care	186	0.064	0.768	0.794	74
Clothes	291	0.093	0.086	0.062	133
Clothes (men)	291	0.038	0.130	0.128	66
Clothes (women)	291	0.017	0.081	0.019	5
Coats (men)	300	0.001	0.003	0.004	15
Coats (women)	300	0.002	0.000	0.000	10
Coffee	333	0.000	0.283	0.300	48
Dental services	437	0.004	0.613	0.867	174
Dress (women)	396	0.019	0.196	0.002	9
Educational books	138	0.047	0.589	0.559	30
Eggs	437	0.019	0.000	0.000	8
Electricity	437	0.019	0.247	0.226	15
Fats and oils	333	0.064	0.169	0.140	58
Fish and seafood	257	0.093	0.548	0.521	58
Flour	342	0.109	0.069	0.056	32
Footwear	437	0.012	0.021	0.010	49
Footwear (men)	257	0.019	0.031	0.037	110
Footwear (women)	342	0.046	0.023	0.033	44
Fresh fruit	437	0.010	0.918	0.771	13
Fuel oil	437	0.004	0.079	0.077	35
Furniture	437	0.053	0.178	0.173	71
Gas	437	0.001	0.012	0.013	7
Gasoline	437	0.002	0.078	0.091	50
Housekeeping supplies	437	0.036	0.756	0.597	99
Intracity transport	341	0.327	0.084	0.082	156
Jewelry	234	0.088	0.057	0.055	62
Laundry equipment	257	0.011	0.419	0.434	59
Liquor	341	0.048	0.188	0.272	79
Margarine	437	0.067	0.047	0.042	35
Medical care services	257	0.000	0.750	0.733	128
Medical care supplies	333	0.078	0.740	0.789	130
Non-prescription drugs	234	0.030	0.477	0.436	75
Pants	301	0.035	0.040	0.013	15
PC	102	0.033	0.071	0.065	187
Personal care products	425	0.095	0.482	0.457	107
Photo equipment	257	0.170	0.635	0.626	94
Pork	333	0.254	0.074	0.220	11
Potatoes	437	0.007	0.036	0.000	14
Poultry	437	0.030	0.001	0.003	22
Prescription drugs	257	0.064	0.833	0.830	169
Reading materials	342	0.006	0.204	0.159	112
Rent	282	0.204	0.697	0.659	100
Restaurant meals	437	0.088	0.333	0.289	58
Shelter	333	0.001	0.602	0.568	98
Sport equipment	333	0.046	0.100	0.096	169
Sport vehicles	333	0.092	0.085	0.088	566
Sugar and sweets	425	0.001	0.233	0.218	48
Tobacco	437	0.007	0.698	0.648	79
Tomatoes	437	0.000	0.726	0.004	4
Toys	257	0.068	0.141	0.554	–
Tuition	342	0.008	0.190	0.021	16
Video	257	0.261	0.608	0.580	378
Watches	234	0.064	0.002	0.003	48
Water and sewerage	398	0.296	0.814	0.801	54
Wine	398	0.068	0.349	0.421	85

Dependant variable: log of US-CA good-specific real exchange rate, monthly. [a] Test requires stationarity. [b] McKinnon asymptotic p-values. [c] Calculated using impulse response functions, given optimal lag structure.

Table 3: Long run properties: linearity and stationarity

	STD	AR(1) half life	TAR(2,1,1) threshold	TAR(2,1,1) half life	AR(p) half life	TAR(2,p,d) threshold	TAR(2,p,d) half life
Foods	0.147	45	0.146	22	41	0.083	29
Vice goods	0.188	72	0.149	70	55	0.144	149
Clothing and footwear	0.075	20	0.027	23	26	0.022	31
Tech stuff	0.085	156	0.079	33	540	0.063	27
Fuels	0.149	51	0.097	43	50	0.069	50
Medical and chemical	0.146	235	0.193	332	244	0.105	527
Cars and car parts	0.074	20	0.039	22	27	0.035	26
Laundry appliances	0.099	94	0.074	111	98	0.154	45
Furniture	0.092	59	0.127	43	67	0.145	60
Services	0.133				224	0.065	160
CPI-RER	0.111		0.071	1733	162	0.012	193

Table 4: BAND-TAR Summary

	OLS				Tobit		$\beta^{g,in}$	Decline in transport costs			Robustness		
	All		Non-linear only		Linearity control		**estimated**	All	Non-linear	Tobit			NAE
	1†	2†	3	4	5	6	7†	8†	9	10	11	12	13†
Const.	**9.8*****	**10*****	**10*****	**8.7*****	**7.3****	**7.9*****	**15*****	**10*****	**10****	4.7	**-1.73*****	**10*****	**10*****
	(0.00)	(0.00)	(0.008)	(0.00)	(0.017)	(0.00)	(0.00)	(0.01)	(0.019)	(0.019)	(0.000)	(0.000)	(0.000)
P/W	**-0.056****	**-0.037*****	**-0.058****	**-0.03****	**-0.03***	**-0.03****	**-0.05*****	**-0.06*****	**-0.06*****	**-0.06***	–	–	**-0.03*****
	(0.029)	(0.004)	(0.026)	(0.015)	(0.08)	(0.05)	(0.002)	(0.006)	(0.00)	(0.09)			(0.001)
CPI^{weight}	**-1.9*****	**-1.7*****	**-1.8***	-1.3	**-6.3****	**-6.2****	**-2*****	**-3.1*****	**-3.9***	**-4.6***	**-.33****	**-0.28***	**-1.2*****
	(0.005)	(0.002)	(0.069)	(0.147)	(0.017)	(0.03)	(0.006)	(0.008)	(0.072)	(0.055)	(0.040)	(0.10)	(0.007)
Tariff	-10	–	-10	–	-2.3	–	–	-24	9.8	–	–	–	–
	(0.255)		(0.69)		(0.933)			(0.45)	(0.8)				
NTB	-20	-17	-19	–	-17	–	**-27***	9	-18	-5.9	**-5.2*****	–	**-31*****
	(0.116)	(0.114)	(0.182)		(0.213)		(0.096)	(0.56)	(0.24)	(0.78)	(0.01)		(0.01)
Sectoral infl.	41	–	38	–	44	–	–	25	18	**97****	–	–	–
	(0.255)		(0.37)		(0.132)			(0.47)	(0.59)	(0.046)			
HHI	0.0005	–	0.0003	–	–	–	–	0.002	**0.006*****	0.001	–	–	–
	(0.77)		(0.86)					(0.26)	(0.01)	(0.68)			
log(P/W)	–	–	–	–	–	–	–	–	–	–	**-0.54*****	–	–
											(0.000)		
log(P/V)	–	–	–	–	–	–	–	–	–	–	–	**-0.36*****	–
												(0.000)	
N	40	47	39	46	47	47	47	35	25	37	47	47	41
LogL, R^2	0.29	0.20	0.29	0.16	35.8	34.4	0.16	0.30	0.40	14.5	0.47	0.30	0.15
p-val LR χ^2, F-prob	0.01	0.03	0.07	0.03	0.049	0.001	0.008	0.01	0.007	0.10	0.000	0.000	0.000

Dependant variable (except regressions 8-10): threshold estimate in a Band-TAR model for real exchange rates of 52 good categories between US and Canada (log(threshold) in regressions 11 and 12). Dependant variable (regressions 8-10): threshold estimate in a Band-TAR model for real exchange rates of goods categories between US and Canada imposing a decline in threshold at the rate of decline in US-CA transport costs as estimated by Novy (2006). P/W is ratio of price (in USD, 2000) to weight (in kg). P/V is ratio of price to volume (in m^3). CPI^{weight} is the expenditure weight of the good in CPI (a measure of market size). HHI is the value-added Herfindahl-Hirschman index based on 6-digit 1997 NAICS codes. Tariff is the 1989 US-Canada tariff rate based on 8-digit HTS collected by John Romalis. NTB is a measure of non-tariff barriers from World Bank's Trade, Production and Protection database. Sectoral inflation is average absolute annual CPI inflation rate in relevant sector. NAE regression excludes alcohol (liquor, beer, wine) and energies (gasoline, natural gas) due to limited tradability. p-values in parentheses. Tobit regression assigns 0 to threshold estimate for any good for which linearity cannot be rejected by Tsay's test. A * denotes 10%, ** 5% and *** 1% significance. † denotes a regression with heteroscedasticity-consistent standard errors following a rejection of homoscedasticity.

Table 5: Threshold regressions, US-Canada

	OLS		Tobit		HP-detrended	
	All	Non-linear only	Non-linear	Non-linear & stationary	OLS	Tobit Non-linear
	1†	2†	3	4	5	6
Constant	**1.9****	**1.8*****	**1.9*****	**2.3*****	**0.2***	**-0.87*****
	(0.032)	(0.000)	(0.008)	(0.001)	(0.06)	(0.000)
P/W	**-0.015*****	**-0.015*****	**-0.015*****	**-0.015*****	-0.002	**-0.0032***
	(0.000)	(0.001)	(0.009)	(0.004)	(0.158)	(0.10)
ER volatility	1.26	1.1	0.8	0.58	**0.72*****	**1.1** ***
	(0.327)	(0.406)	(0.46)	(0.59)	(0.007)	(0.006)
Distance	**0.00024****	**0.00027****	0.00013	**0.00018***	**0.00044*****	**0.00044*****
	(0.021)	(0.015)	(0.26)	(0.085)	(0.000)	(0.000)
Refrig. dummy	**-1.8*****	**-2***	-0.62	-0.6	–	–
	(0.005)	(0.072)	(0.60)	(0.59)		
NTB	-2.5	-2.3	-2.6	-3	–	–
	(0.2)	(0.317)	(0.26)	(0.17)		
Sectoral infl.	**301*****	**357*****	**238*****	**234*****	–	–
	(0.002)	(0.001)	(0.000)	(0.00)		
R^2/LogL	0.18	0.22	392.99	442.8	0.39	571.6
F-stat	0.000	0.000	–	–	0.000	–
N	324	279	323	323	324	324

Dependant variable: Band-TAR threshold estimate for real exchange rates of 35 product categories between US, UK, Canada, Germany and France. P/W is a ratio of price (in USD, 2000) to weight (in kg). Distance is the greater circle distance between capital cities in km. ER volatility is the standard deviation of relevant monthly bilateral nominal exchange rate. Refrigeration dummy =1 for beef, cheese, eggs, fish and seafood, poultry, fresh fruits, margarine and tomatoes. NTB is a measure of non-tariff barriers obtained from World Bank's Trade, Production and Protection database. Sectoral inflation is average absolute annual CPI inflation rate in relevant sector. p-values in parentheses. A * denotes 10%, ** 5% and *** 1% significance. † denotes a regression with heteroscedasticity-consistent standard errors following a rejection of homoscedasticity.

Table 6: Threshold Regressions, Five Countries

	All		Robustness	
		No alcohol	No alc, energy	Non-lin. only
	1	2	3	4
Constant	**4.5*****	**4.3*****	**4.3*****	**4.4*****
	(0.00)	(0.000)	(0.00)	(0.00)
P/W	**-.014*****	**-0.013*****	**-0.01*****	**-0.01*****
	(0.00)	(0.00)	(0.00)	(0.00)
Refrig. dummy	**-0.76****	**-0.66***	–	**-0.85****
	(0.036)	(0.064)		(0.016)
Sector. infl.	**-9.6*****	**-8.9****	**-14.8*****	**-8.1****
	(0.008)	(0.013)	(0.00)	(0.017)
R^2	0.38	0.35	0.41	0.43
F-stat(prob)	0.00	0.000	0.000	0.000
N	45	42	39	35

Dependant variable: Logarithm of half-life estimated in a Band-TAR model for real exchange rates of 52 good categories between US and Canada. P/W is a ratio of price (in USD, 2000) to weight (in kg). Refrigeration dummy =1 for beef, cheese, eggs, fish and seafood, poultry, fresh fruits, margarine and tomatoes. Sectoral inflation is the average absolute annual CPI inflation rate in relevant sector. Regressions 2 and 3 exclude alcohol (beer, liquor, wine) and energy (gasoline, natural gas), respectively, due to limited tradability. p-values in parentheses. A * denotes 10%, ** 5% and *** 1% significance.

Table 7: Half life regressions

	All		Non-linear only		HP-detrended
	1	2	3	4	5
Constant	**1.2*****	**1.2*****	**1.1*****	**1.1*****	**2.2*****
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
P/W	-0.00032	–	-0.00025	–	**-0.0007***
	(0.32)		(0.59)		(0.096)
Stowage	–	**-0.003*****	–	**-0.003****	–
		(0.007)		(0.045)	
ER volatility	**0.2****	**0.2****	**0.3*****	**0.28*****	0.088
	(0.031)	(0.017)	(0.001)	(0.001)	(0.34)
Distance	**0.00002***	**0.00002***	**0.00002*****	**0.00003*****	**0.00003*****
	(0.09)	(0.063)	(0.006)	(0.005)	(0.000)
Refrig. dummy	**-0.27*****	**-0.2****	**-0.29*****	**-0.24*****	-0.08
	(0.004)	(0.02)	(0.001)	(0.009)	(0.39)
CPI^{weight}	0.027	0.022	0.023	0.02	**-0.05****
	(0.19)	(0.3)	(0.29)	(0.38)	(0.044)
NTB	0.11	0.08	0.1	0.08	-0.2
	(0.49)	(0.62)	(0.58)	(0.65)	(0.27)
Sectoral infl.	**11*****	**12*****	**8.8*****	**9.5*****	-2.6
	(0.006)	(0.00)	(0.006)	(0.003)	(0.44)
R^2/LogL	0.12	0.14	0.16	0.17	0.07
F-stat	0.002	0.000	0.000	0.000	0.000
N	270	270	232	232	320

Dependant variable: Logarithm of half-life estimated in a Band-TAR model for real exchange rates of 35 product categories between US, UK, Canada, Germany and France. P/W is a ratio of price (in USD, 2000) to weight (in kg). A stowage factor of a cargo is the ratio of weight to stowage space (the unit is ton/m^3) required under normal conditions, including all packaging. Distance is the greater circle distance between capital cities in km. ER volatility is the standard deviation of relevant monthly bilateral nominal exchange rate. Refrigeration dummy =1 for beef, cheese, eggs, fish and seafood, poultry, fresh fruits, margarine and tomatoes. CPI^{weight} is the expenditure weight of the good in CPI (a measure of market size). NTB is a measure of non-tariff barriers from World Bank's Trade, Production and Protection database. Sectoral inflation is average absolute annual CPI inflation rate in relevant sector. p-values in parentheses. A * denotes 10%, ** 5% and *** 1% significance.

Table 8: Half-life Regressions for Five Countries