Deviations from the Law of One Price in Japan

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Abstract

Using 25 years of monthly data on individual Japanese retail prices, we study the behavior of product-specific Law of One Price (LOP) deviations. Individual tradable products, compared with nontradables, are more likely to have different distributions of LOP deviations across cities. Their distributions are also more likely to change over time. Individual LOP deviation series are found to display considerable persistence and there is limited evidence that tradability enhances price convergence. In addition, deviations from the LOP are found to display nonlinear trends, and these trends are not linearly related to a product's tradability. For individual products, LOP deviations are affected by their own inflation rates and, to a lesser extent, by aggregate inflation, output variations, and monetary variability. Interestingly, the trend behavior remains significant in the presence of these economic variables.

JEL Code: F31, F34, F36.

Keywords: price dispersion, tradability, asymmetric inflation effects, market integration.

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1. Introduction

We examine the properties of monthly retail price data from selected Japanese cities. Instead of price indexes, actual prices are used to infer the relevance of the Law of One Price (LOP) and the implied evolution of market integration in Japan. The choice of Japanese price data is motivated by the benefits of using intra-national data and the characteristics of the Japanese economy.

According to the LOP, prices of identical products in different geographic locations should be the same when they are converted into the same currency unit. Most empirical studies that compare international prices or price indexes, however, find large and persistent deviations from the LOP.[1] The convergence of either international prices or price indexes is known to be severely hindered by factors including trade barriers, differential national policies, and exchange rate variability. In our exercise, the use of intra-national price data alleviates the effects of these impediments and allows a less ambiguous interpretation. Further, with actual prices instead of price indexes, we can assess absolute rather than relative price convergence.

There are some extant studies examining price convergence within the US (Cecchetti, Mark, and Sonora, 2002; Engel and Rogers, 2001; Parsley and Wei, 1996; O'Connell and Wei, 2002). While the US experiences are relevant, the results from other countries are required to establish the generality of price convergence behavior. Since Japan is the second largest economy in the world, empirical evidence from the Japanese data should broaden our understanding of price convergence behavior. Indeed, relative to the US, Japan is a more homogenous economy in a few important aspects. For instance, the consumption tax is completely harmonized across all regions in Japan. It is also perceived that the consumption pattern is more uniform within Japan than within the US. Thus, the regional price dispersion in Japan is less subject to the effects of differential taxes and dis-similar consumption patterns.

Our focus on individual product prices is related to a number of antecedent studies. For example, Crucini and Shintani (forthcoming) use retail price data from the Economist Intelligence Unit's *Worldwide Cost of Living Survey* and report an alternative result of the border effect on real exchange rate persistence. Crucini, Telmer, and Zachariades (2005) examine four years of price data on 1,800 products from European countries and find that international price

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[1] Isard (1977) is among the first to empirically evaluate the LOP condition.

dispersion is negatively (positively) related to the tradability (non-traded input share) of the product. Bergin and Glick (2007) reveal an interesting U-shape pattern in price dispersion over time from the *Worldwide Cost of Living Survey* data. The result is quite surprising in view of the continuous reduction in trade barriers and advances in transportation technology. In a similar vein, Rogoff, Froot, and Kim (2001) do not find a significant decline in the magnitude, volatility, and persistence of deviations from the LOP in a dataset that spans over 700 years.[2]

In the current exercise, we work with actual Japanese retail prices obtained from the official *Retail Price Survey*. These survey prices are prices of narrowly defined consumer products (and services) in selected Japanese cities and are collected for compiling consumer price indexes. These prices are quite comparable across cities because the *Survey* has quite precise references to a product's quality (grade) and quantity (package). Thus, we believe that the measurement errors associated with these actual Japanese retail prices are not as severe as those associated with actual price data complied by, for instance, the Economist Intelligence Unit's *Worldwide Cost of Living Survey* and the American Chamber of Commerce Association.

In this exercise, the basic price variable is a relative price variable. To address the numeriare issue, the basic price variable is defined by, for each time period, the price of a product in a city relative to the average price of the product across all the cities. For brevity, we call the basic price variable the LOP deviation, which measures a product's city-specific deviation from the LOP.

Our empirical analyses focus on the properties of the product-specific LOP deviations. For each product, we examine a) the cross-city distribution of its LOP deviations, which offers a general description of the LOP deviation behavior, b) the persistence of city-specific LOP deviations, and c) a summary measure of LOP deviation behavior given by the average of its absolute LOP deviations across all the cities.

To anticipate the results, we find that the product-specific cross-city distributions of LOP deviations tend to differ from each other. For each time period, products fall within the nontradable category have a higher chance of displaying a similar distribution than those within the tradable group. Towards the end of our sample period, however, the chance of displaying a

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2 Other studies that examine prices of narrowly defined products include Crownover, Pippenger and Steigerwald (1996), Engel and Rogers (2004), Haskel and Wolf (2001), Lutz (2004), and Parsley and Wei (1996, 2001).

similar distribution is higher for both groups. For each product, the probability of its distribution of LOP deviations to change over time increases with its tradability. The evidence suggests that the tradables and nontradables have different patterns of LOP deviations both at a given point in time and over time.

On persistence, the unit root test results go against the general notion that tradability enhances price convergence. Indeed, both the unit root test results and the persistence measure based on autoregressive coefficient estimates do not lend unambiguous support to the view that, compared with nontradables, tradables are more likely to have a faster rate of convergence to the LOP.

For each product, the average of its absolute LOP deviations across all the cities is our summary measure of the magnitude of LOP deviations. This product-specific summary measure suggests that deviations from the LOP in Japan are quite substantial – the average (absolute) deviation exceeds 10 percent even for the most tradable products in our sample. Furthermore, individual products' deviations from the LOP exhibit linear, quadratic, and cubic trends. Indeed, there are both positive and negative trends in these LOP deviation series. If the degree of deviation from LOP is associated with the level of market integration, then the finding does not support the notion that the internal Japanese market is uniformly more integrated over time. The evidence on the association between trend behavior and tradability is quite weak.

In searching for economic factors determining the evolution of product-specific LOP deviations, we appeal to price theory and identify asymmetric effects of a product's own inflation rate – a result that is in accordance with the pricing behavior under imperfect information and price stickiness. To a lesser extent, individual products' LOP deviations are affected by aggregate inflation. Other macro variables including the oil price and uncertainties of output and money play only a very limited role. Interestingly, the trend behavior remains significant in the presence of these economic variables. In other words, the behavior of LOP deviations is jointly affected by some economic and some deterministic factors.

In sum, the relatively long individual Japanese retail price series reveal some intricate properties of LOP deviations. While tradability affects the distribution of LOP deviations, it does not have an unambiguous effect for the persistence of LOP deviations. Product-specific LOP deviations tend to display nonlinear patterns that are not captured by selected economic variables. The use of data on individual products also highlights the heterogeneity of LOP deviations across products – even within individual tradability categories.

The reminder of the paper is organized as follows. The price data used in the exercise are described in the next section. In section 3, we compare individual product's distributions of LOP deviations and study their time variability. Unit root tests are used to assess persistence. Section 4 reports analyses of the behavior of a product's LOP deviations measured by its mean absolute LOP deviation. The section documents both the trend properties and the economic determinants of individual LOP deviation series. Some concluding remarks are offered in Section 5.

2. Data Description and Descriptive Statistics

2.1 *Data Description*

The individual retail price data were drawn from the *Retail Price Survey* published by the Statistical Bureau of the Ministry of Internal Affairs and Communications of Japan – see the Bureau's website (http://www.stat.go.jp/english/data/kouri/index.htm) for detailed information about the survey. The survey was initiated in June 1950 to collect nation-wide information on retail prices of specific goods and services for compiling the consumer price index. The prices are recorded for quite precisely defined consumer products such as "hen eggs (color: white, size L, sold in pack of 10)," "men's undershirt (short sleeves, knitted, 100% cotton, [size] around the chest 88-96cm/MA (M), white, ordinary quality, excluding special processed goods)," and "permanent wave charges (including shampoo, cut, blow or set) for short hair." The specificity of product definition enhances price comparability and minimizes the role of product heterogeneity in explaining price dispersion across geographic locations.[3]

The coverage of cities and products is revised from time to time. By 2005, the survey covers a maximum of 167 locations and 530 consumer products. The sample considered in the current study reflects a trade-off between coverage and data availability. Our choice of data series is constrained by the changes (additions and deletions) of surveyed consumer products and the prevalence of missing observations. In the pre-1981 period, for example, a large number of products have significant occurrences of missing observations. At the end, we settled with a dataset that comprises prices on 86 consumer products from 67 cities between January 1981 and

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[3] However, the perception of heterogeneity may be induced by factors not controlled for in the survey including the characteristics of the store in which the products are sold.

April 2005. Thus, our dataset has 5,762 (= 86x67) monthly retail price series and each series has 292 monthly observations.

The 67 cities in the sample distribute throughout Japan. Each of the 47 prefectures in Japan is represented by at least one city in the sample. Prefectures are administrative regions that roughly correspond to States in the US. The list of cities is given in Table A.1 of the Appendix.

We classified the 86 consumer products into four tradability categories: 1) services that include foods and drinks served at restaurants, and other nontradable items, 2) meat, fresh produces, dairy products, and other perishable food items; 3) storable foods and drinks; and 4) manufacturing products. Loosely speaking, categories 2 to 4 are formed based on a product's perishability/durability. There are 17, 30, 18, and 21 products listed under these four categories. It is assumed that a product's tradability increases with its durability. Thus, in our exercise, the degree of tradability increases with the tradability index that is given by the category labels 1, 2, 3, and 4. For convenience, we refer to products under categories 1 and 2 as nontradables and those under 3 and 4 as tradables. We will present empirical results for individual tradability categories and for tradable and nontradable dichotomy. Table A.2 in the Appendix lists these consumer products and their tradability labels.

A caveat is in order. Our tradability classification suffers from the usual criticisms including the fact that all retail prices have a nontradable price component.[4] In some extant studies, only services items are labeled nontradables. In the current exercise, we consider the tradable and nontradable groups that have similar numbers of products to facilitate statistical analyses. Our classification does not appear to qualitatively affect the inferences.

2.2 Descriptive Statistics

The generic notation of the price of product *i* in city *j* at time *t* is $P_{i(k),j,t}$, where *k* (= 1, 2, 3, and 4) gives the product's tradability index defined above. Our study of LOP deviations is based on a product's price relative to the average price across all the cities

$$p_{i(k),j,t} = \ln P_{i(k),j,t} - \Sigma_{j=1}^{N} \ln P_{i(k),j,t} / N , \quad (1)$$

[4] Crucini, Telmer, and Zachariades (2005), for example, used the input-output table to identify a product's tradable and nontradable components. However, there is no direct match between the products in our sample and the entries in the Japanese input-output table. Further, we do not have the Japanese input-output data that cover our sample period.

where N = 67 is the number of cities in the sample. In essence, the average price instead of the price from a specific city is used as the numeriare to define LOP deviations; see Crucini, Telmer, and Zachariades (2005) and O'Connell and Wei (2002). The use of log prices is in accordance with the common practice in literature. For product i in city j, the price $p_{i(k),j,t}$ measures its deviation from the LOP that is given by the (percentage) difference between its price and the average price of the same product across all cities in the sample at time t. For brevity, we call $p_{i(k),j,t}$ the LOP deviation variable henceforth. Under ideal conditions, the LOP holds and $p_{i(k),j,t} = 0$. In the absence of ideal conditions, $p_{i(k),j,t} \neq 0$ and the distribution of $p_{i(k),j,t}$ can be used to infer the behavior of LOP deviations.

Some descriptive statistics of $p_{i(k),j,t}$ are given in Table 1. The entries in the row labeled "All" are obtained from pooling observations across all products (i), cities (j), and time periods (t). The other rows give the summary statistics for the specified tradability categories.

Because $p_{i(k),j,t}$ has a zero mean by construction, we reported its mean absolute value. The variance, reported in the third column, is an alternative measure of the variability of LOP deviations. Both the mean absolute value and the variance gauge a general degree of deviation from the LOP, with the latter measure imposing a heavier penalty on larger deviations.

The results in the tables do not suggest a definite link between tradability and the degree of deviations from the LOP. Under the dichotomic tradable and nontradable classification scheme, the prices of tradables (k = 3, 4) give a mean absolute value smaller than the nontradables (k = 1, 2). For individual categories, however, the k = 2 category has the largest mean absolute value while the k = 3 and k = 2 categories have the largest sample variance. The most tradable group (k = 4) has the smallest mean absolute value but the least tradable group (k =1) has the smallest variance. Apparently, these descriptive statistics do not reveal a (linear) relationship between tradability and LOP deviations.

To further investigate the small price variability exhibited by least tradable (k =1) group, we reported the descriptive statistics from the sub-categories of administratively controlled prices and non-controlled prices at the bottom of the Table. The breakdown indicates that, compared with the non-controlled prices, administratively controlled prices are indeed associated with a smaller mean absolute value, but not a smaller variance. Further, excluding items with administrated prices does not alter the relative ranking of the k=1 category vis-à-vis other categories in terms of the sizes of their mean absolute values and variances.[5]

For the case of $k = 1$, the LOP deviation gives a positive sample skewness estimate. Apparently, the large positive LOP deviations that lead to a positive skewness estimate for the least tradable group are concentrated among the administratively controlled prices. Indeed, for the products in this group that are not subject to price control, their skewness estimate is comparable to the one displayed by the most tradable $k = 4$ group – both have a small and negative skewness estimate. The two middle groups, with $k = 2$ and 3, on the other hand, have a relatively large negative skewness estimate; indicating that their LOP deviations are characterized by some large negative deviations from the cross-city average prices. Again, we do not observe a simple linear relationship between tradability and skewness of LOP deviations.

The kurtosis coefficient that describes the peakedness of the distribution also varies across these four tradability groups. All four groups have a kurtosis coefficient larger than 3; that is, compared with a normal random variable, the individual product-specific LOP deviations have a high concentration around their mean value and, at the same time, a large proportion at the extremes. The magnitude of kurtosis tends to increase with the degree of tradability – indeed, the most tradable group has a coefficient that is at least 35% larger than the other groups.

These descriptive statistics show that products with different degrees of tradability display different patterns of LOP deviations. Nonetheless, these sample statistics reveal no simple linear relationship between the behavior of LOP deviation and tradability. In the subsequent Sections, we offer a more detailed analysis the product-specific LOP deviation. For brevity, we omitted the breakdown of administratively controlled prices and non-controlled prices in the subsequent Sections since it did not qualitatively affect the inferences.

3. Statistical Properties

In this section, we study the statistical properties of the LOP deviation variable $p_{i(k),j,t}$. First, we examine the distribution of $p_{i(k),j,t}$ across cities; that is, the distribution of $\{ p_{i(k),j,t}; j = 1, \ldots, N\}$. Then, we evaluate the persistence of individual LOP deviation series $\{ p_{i(k),j,t}; t = 1, \ldots, T\}$.

5 It is noted that, using US city CPI sub-indexes, Engel and Rogers (2001) find that the traded goods have a larger variance of (proportional) LOP deviations.

3.1 *Patterns of Product-Specific LOP Deviations*

Recall that, for product *i* at time period *t*, $p_{i(k),j,t}$ measures the price differential between city *j* and the average across all the cities. Thus, the pattern of the product-specific LOP deviations can be described by the distribution of $\{ p_{i(k),j,t} ; j = 1, \ldots, N\}$. If two products have a similar distribution, then they have a similar pattern of deviations from the LOP.

Compared with nontradables, are tradables more likely to share a similar pattern of LOP deviations? To address the question, we compare the distributions $\{ p_{i(k),j,t} ; j = 1, \ldots, N\}$ and $\{ p_{i^*(k^*),j,t} ; j = 1, \ldots, N\}$ at a given point of time *t*, for *i* and *i** = 1, …, 86. The nonparametric Kolmogorov-Smirnov test for distribution equality is used to determine if two distributions are the same. A description of the Kolmogorov-Smirnov test is provided in the Appendix. With 86 products, there are 3655 product-pairs. We grouped these 3655 pairs into tradable pairs and nontradable pairs. We also considered the groupings in which the pairs are formed according to their tradability indexes.

Table 2 summarizes the Kolmogorov-Smirnov test results. For simplicity, we conducted the test on data from individual months in four selected years – 1981, 1991, 2001, and 2004. The rejection frequencies based on the 95% critical value are presented. Each rejection frequency is compiled by aggregating results from individual months of the year. The results for the pairing of tradables and nontradables are not reported for brevity. As expected, the rejection frequencies of these pairs are in the range defined by those of the tradable pairs and nontradable pairs.

A few observations are in order. First, across all product categories, there is a general tendency that the rejection frequency declines over time. In other words, the distributions of LOP deviations are becoming more similar over time within each product category. It should be noted that, however, the result does not imply that the deviation from the LOP is more or less severe over time. It merely indicates that the increasing chance of observing similar deviation behavior.[6]

Second, the rejection rate tends to be high when both products are in the tradable category and to be low when both are in the nontradable category (Panel A). That is, compared

[6] Note that the potential link between arbitrage and tradability has an implication for the deviation from the LOP but not necessarily for the distribution of LOP deviations.

with tradables, the nontradables have a higher chance to display a similar LOP deviation distribution and, thus, a less heterogeneous profile of LOP deviations. Indeed, with the exception of the k =1 case, the rejection frequency decreases with the tradability index (Panel B). That is, highly tradable products are more heterogeneous in their patterns of LOP deviations.

We are not aware of a theory that elaborates the distribution of LOP deviations. Our conjecture is that the prices of nontradables are heavily influenced by local conditions including land prices, wages, and market structures. If the nontradables are facing similar regional distributions of local factors that determine their prices, then their patterns of LOP deviations will appear to be relatively homogenous. Nonetheless, it is noted that the argument does not explain the difference in the degrees of heterogeneity observed for the k =1 and k =2 categories.

The local factors interpretation also has an implication for the pattern of LOP deviations over time. The geographic distribution of the local factors is quite stable over time in Japan – for instance, the land prices and wages in Tokyo and other metropolitan areas have been consistently higher than those in a typical regional city such as Niigata. If it is the case, a nontradable product will display a stable pattern of LOP deviations over time. Indeed, it is found in the next subsection that nontrables are less likely to experience changes in their patterns of LOP deviations over time.

To assess if the test results significantly depend on the way products are paired up, we conducted the contingency table χ^2 test for independence. The χ^2 test statistics reported in Panel C reject the null hypothesis of independence. That is, the rejection frequencies recorded for different groups of product-pairs are significantly different from each other, and the LOP deviations of tradables are more likely to distribute differently than those of nontradbles.

3.2 Patterns of LOP Deviations across Time

In the previous subsection, we compared the distributions of LOP deviations of two products at a given point of time. In this subsection, we assess a product's distribution of LOP deviations at different points of time. Conceivably, during the sample period, advances in, say, communication and transportation technologies and changes in market structure affect the price behavior of different products in different ways. To gauge the time variability of a product's city-specific LOP deviations, we compare the empirical distributions $\{ p_{i(k),j,t}; j = 1, \ldots, N\}$ and

{ $p_{i(k),j,t^*}$; $j = 1, \ldots, N$} observed at time t and time t^* using the Kolmogorov-Smirnov test. The results are used to infer the time stability of the distribution. The distributions of LOP deviations observed every month in 1981, 1991, and 2001 are compared. Table 3 summarizes the results.

It is apparent that the distribution of LOP deviations of tradables, compared with the one of nontradables, has a higher level of time variability. For instance, in the 20-year time span between 1981 and 2001 (Panel A of Table 3), a significant change in the distribution of LOP deviations is detected in 37% of tradable products. During the same period, however, only 5% of nontradables displayed significant changes in their distributions – indeed, the rejection rate is the size of the test. Comparing the two 10-year periods, the rejection rates in Panel B are larger than those in Panel C; that is, the distribution of LOP deviations has a lower degree of variability in the latter 10-year period.[7] As expected, the chance of a distribution to experience changes increase with time horizon, and the rejection rates recorded for each of the two 10-year periods are smaller than the corresponding ones for the 20-year period. Across the three panels, the $k = 4$ category gives a noticeably high rejection rate and the $k = 2$ category has a rate that is lower than the size of the test. Similarly to what is found in the previous subsection, if we exclude the least tradable group ($k = 1$), the results suggest that the rejection rate is positively associated with the degree of tradability.

The contingency table χ^2 test results reported in the notes to the Table affirm the presence of tradability effect. In all cases, the contingency table test rejects the null hypothesis of independence at the 1% level of significance. That is, compared with a less tradable product, a product with a higher degree of tradability is more likely to have a distribution of LOP deviations that varies over time. Apparently, the factors that determine the evolution of LOP deviations are different across the tradability categories and those affecting tradables tend to be more variable.

Conceivably, the price dynamics of tradables, in contrast with nontrables, are more heavily influenced by, say, technological innovations, which have evolved quite rapidly in the last twenty or thirty years. For instance, technological advances have a significant implication for computer price variation but not for, say, hair cut charges. The increasing trend of global integration also has created a different landscape for the market of tradables. At the same time, if

7 For European cities, Engel and Rogers (2004) find that price convergence occurred

prices of nontradables are mainly affected by local cost factors that do not substantially change over time, then their LOP deviations will display less time variability than tradables'.

Combining these results with those from Table 2, we infer that, with the exception of the k =1 category, the degree of tradability has a significant implication for the heterogeneity of LOP deviations – both between products and over time. In passing, we note the "unique" behavior of the least tradable k =1 category. Compared with those in the k =2 cateogry, the products in this category have a (relatively) more *heterogeneous* pattern of LOP deviations at a given point of time and over time. At the moment we do not have a good explanation for the phenomenon.

3.3 Persistence

For a product defined by $i(k)$ and j , the variable $p_{i(k),j,t}$ measures it's departure from the LOP at time t. The series { $p_{i(k),j,t}$; t = 1, …, T}, then, traces out the temporal evolution of the product's deviations from the LOP. If the deviation is of transitory nature, then the LOP deviation is expected to diminish over time and the price converges according to the LOP. In the current subsection, we investigate if { $p_{i(k),j,t}$; t = 1, …, T} exhibits unit-root persistence. If $p_{i(k),j,t}$ does not have unit-root persistence, then the price of the product has a tendency to move towards its average value in the long run. On the other hand, if it exhibits unit-root persistence, then the LOP does not hold even in the long run.

To improve power performance, we use a modified Dickey-Fuller test known as the ADF-GLS test (Elliott, Rothenberg, Stock, 1996). The ADF-GLS$^{\tau}$ test that allows for a linear time trend is based on the following regression:

$$(1-L)\,p^{\tau}_{i(k),j,t} \;=\; \alpha_0 p^{\tau}_{i(k),j,t-1} + \sum\nolimits_{m=1}^{n} \alpha_m (1-L)\,p^{\tau}_{i(k),j,t-m} + \varepsilon_t \qquad (2)$$

where $p^{\tau}_{i(k),j,t}$ is the locally detrended process under the local alternative of $\bar{\alpha}$ and is given by $p^{\tau}_{i(k),j,t} = p_{i(k),j,t} - \tilde{\gamma}' z_t$ with z_t = (1, t)'. $\tilde{\gamma}$ is the least squares regression coefficient of $\tilde{p}_{i(k),j,t}$ on $\tilde{z}_t$, where $(\tilde{p}_{i(k),j,1}, \tilde{p}_{i(k),j,2}, \ldots \tilde{p}_{i(k),j,T}) = (p_{i(k),j,1}, (1-\bar{\alpha} L)\, p_{i(k),j,2}, \ldots, (1-\bar{\alpha} L)\, p_{i(k),j,T})$, $(\tilde{z}_1, \tilde{z}_2, \ldots, \tilde{z}_T) = (z_1, (1-\bar{\alpha}L) z_2, \ldots, (1-\bar{\alpha}L) z_T)$, and L is the lag operator. The local alternative $\bar{\alpha}$ is defined by $\bar{\alpha}$ =1 + $\bar{c}$ / T for which $\bar{c}$ is set to -13.5. In implementing the test, the lag

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mainly in the pre-1999 era.

parameter n is chosen to make the error term ε_t a white noise process. The unit root hypothesis is rejected when the ADF-GLS test statistic, which is given by the usual t-statistic for $a_0 = 0$ against the alternative of $a_0 < 0$, is significant.

Before discussing the test results, we should point out that unit root tests are notorious for their low power to differentiate a unit root process from a stationary but highly persistent one. Thus, we prefer to interpret the non-rejection of the unit root hypothesis as a confirmation of the presence of strong persistence rather than as an unambiguous evidence of a unit root in the data.

The results of applying the ADF-GLS test to individual LOP deviation series $\{ p_{i(k),j,t}; t = 1, \ldots, T\}$ are summarized in Table 4. Using a 10-percent level finite sample critical value, 57% of the series reject the unit root null hypothesis. The deviation from the LOP appears quite persistent for the remaining 43% of the series.

It is commonly perceived that tradability enhances price convergence via arbitrage. Thus, we expect tradables' LOP deviations, compared with nontradables', to display less persistence and, thus, to yield a higher rejection rate of the unit root hypothesis. The results in Table 4, however, do not lend strong support to this view. The broad tradable category yields a 51% rejection rate, which is lower than the 62% garnered by nontradables (Panel A).

Panel B presents some intricate phenomena. The results from the $k = 4$ to $k = 2$ categories indicate that the rejection rate decreases with tradability. That is, tradability intensifies the persistence of LOP deviations and does not enhance price convergence. However, this observed link between tradability and persistence does not extend to the least tradable $k = 1$ category. The $k = 1$ category yields the weakest evidence of convergence with the lowest rejection rate at 47% (but the rate is very close to the one recorded from the most tradable $k = 4$ category). The $k = 2$ category has a noticeably high rejection rate of 70%, which is 13% to 23% higher than the other three categories. That is, the products in this category display the strongest evidence of the LOP. It is not clear why the products in the $k = 2$ category that includes perishables such as fruits, vegetables, and dairy products have a level of LOP deviation persistence that is lower than, say, the manufacturing products in the $k = 4$ category. *A priori*, we perceive that the manufacturing products can be transported around quite easily in response to price differentials. The result, however, is in accordance with those reported in Choi and Matsubara (2007), who used the Japanese consumer price sub-indexes and found that relative prices of perishables are less persistent than those of household durables.

We also considered an alternative measure of persistence given by the sum of autoregressive coefficients (SARC), α_m 's, in (2). The closer the sum to 1, the higher is the degree of persistence. The last column of Table 4 presents the average of the estimates of this persistence measure. The SARC results broadly corroborate the unit root test results; that is, there is no clear evidence that tradability reduces persistence. Again, the *k* = 2 category has the least persistent LOP deviations while the other three categories have comparable SARC estimates that are larger than 0.9.

Overall, the results on the persistence of LOP deviations do not support the notion that tradability enhances price convergence. When we dichotomize the products into the tradables and nontradables groups, the evidence is suggestive of tradability increases persistence. The results for the finer classification scheme, however, suggest that there is no clear monotonic relationship between tradability and persistence.[8] We also note that the LOP deviations of the products under the *k*=2 category exhibit a relatively low level of persistence.

In passing, we also assessed the effect of aggregation on the observed persistence. The ADF-GLS test was applied to the city-specific price series $\{ p_{.,j,t}; t=1, \ldots, T\}$, where $p_{.,j,t} = \Sigma_{i(k)=1}^{M} p_{i(k),j,t} / M$ with *M* denoting the total number of products. In sum, the unit root hypothesis was rejected for 56 of the 67 cities yielding a rejection rate of 84%. The non-rejection rate of 16% is quite close to the size of the test. Our simple aggregation procedure strengthens, instead of weakens, the evidence of the LOP convergence. Apparently, the intra-Japan price data do not display the aggregation bias revealed by real exchange rate data from European countries and the US (Imbs, Mumtaz, Ravn, and Rey; 2005).[9]

4. Product-Specific Average LOP Deviations

In this section, we consider an average measure of LOP deviations given by

$$| \overline{p} |_{i(k),.,t} = \Sigma_{j=1}^{N} | p |_{i(k),j,t} / N , \qquad (3)$$

where |.| is the absolute value operator. Absolute values are used so that positive and negative

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[8] The finding is in contrast with the tradability effect on the persistence of LOP deviations reported in Crucini and Shintani (forthcoming). These authors adopted a different framework to examine international retail price data from the *Worldwide Cost of Living Survey*.

[9] See Chen and Engel (2005), Choi, Mark and Sul (2006), and Crucini and Shintani (forthcoming) for alternative views on aggregation and real exchange rate persistence.

deviations would not cancel out. In essence, for each product, $|\bar{p}|_{i(k),.,t}$ gauges the average size of its LOP deviations and the cross-city price dispersion. We consider it a summary measure of the product's degree of deviation from the LOP. Under the ideal LOP condition, individual $p_{i(k),j,t}$'s equal zero and, thus, $|\bar{p}|_{i(k),.,t}$ is zero. The size of $|\bar{p}|_{i(k),.,t}$ increases with the extent to which the LOP condition is violated – the larger it is, the more severely the LOP is violated.

As a robustness check, we also considered the sample variance of LOP deviations defined by $V(p_{i(k),.,t}) = \Sigma_{j=1}^{N} p_{i(k),j,t}^2/(N-1)$. Compared with the mean absolute deviation, the sample variance imposes a heavier penalty on larger deviations. It turns out that two measures give very similar empirical results. For brevity, we present the results pertaining to the mean absolute deviation measure, $|\bar{p}|_{i(k),.,t}$.

4.1 *Tradability*

A priori, intra-national LOP deviations can be tradability dependent. For instance, an improvement of the efficiency of the distribution system may reduce the inter-city price differentials of tradables but may have little implications for prices of nontradables, such as, haircut services. Indeed, some extant studies argue that price dispersion is negatively related to tradability (Crucini, Telmer, and Zachariades 2005).

In the previous section, we examined the implications of tradability for the LOP behavior by comparing the distributional properties of $p_{i(k),j,t}$ across product categories and over time. In this subsection, we further examine the tradability effect using the regression equation

$$|\bar{p}|_{i(k),.,t} = \alpha_t + \sum_{k=1}^{3} \beta_{k,t} D_{k(i)} + \varepsilon_{i,t}, \qquad (4)$$

where $D_{k(i)}$ is a dummy variable that is set equal to unity when product *i* has a tradability index *k* (=1, 2, 3) and zero otherwise. The product category with the highest level of tradability (*k* = 4) is used as a benchmark and its average absolute deviation from the LOP at time *t* is gauged by α_t. The tradability effect is captured by $\beta_{k,t}$'s that measure the departures from the benchmark. If tradability helps reduce the degree of LOP deviations, then we expect $\beta_{k,t}$'s to be significantly positive and are inversely related to *k* such that $0 < \beta_{3,t} < \beta_{2,t} < \beta_{1,t}$.

We estimated (4) for each period and obtained 292 estimates of each parameter. The time profiles of the coefficient estimates and their *p*-values are plotted, respectively, in Figures 1 and 2. The α_t estimates are larger than 0.1 and are significantly different from zero. In other words, even for products with the highest level of tradability (k = 4), the deviation from the LOP is larger than 10 % on average. The average size of deviation is quite substantial. For instance, Crucini, Telmer, and Zachariades (2005) show that, for tradable products in most of the European Union member countries, their average sizes of LOP deviations are at most a few percentage points. Further, it is noted that the size of the average LOP deviation shows no obvious tendency to decline over time.

The $\beta_{k,t}$ estimates do not offer a strong evidence of tradability effects. Indeed, the smallest dummy coefficient estimate is the $\beta_{1,t}$ estimate – a result that is contradictory to what is expected under the notion that tradability reduces the degree of LOP deviations. Its *p*-values depicted in Figure 2, however, indicate that the effect was never statistically significant. In the 1980s, $\beta_{2,t}$ is generally larger than $\beta_{3,t}$. Since the 1990s, there is a tendency for $\beta_{3,t}$ to overtake $\beta_{2,t}$. In general the $\beta_{k,t}$ estimates are mostly small, positive, and insignificant – the only exception is the $\beta_{2,t}$ estimate, which was positively significant in the 1980s.

We also estimated (4) with data pooled across time assuming that the parameters are time invariant (that is, $\beta_{k,t} = \beta_{k,.}$). The results are quite comparable to those revealed in Figure 1. For instance, all the $\beta_{k,.}$ estimates are significantly positive but quite small – they range from 0.0045 to 0.0262. The $\beta_{1,.}$ and $\beta_{2,.}$ estimates are, respectively, the smallest and the largest estimate. The graphs in Figure 1, however, suggest that the ranking of the $\beta_{2,.}$ and $\beta_{3,.}$ estimates is mainly driven by data in the 1980s. The adjusted R-squares estimate is only at the level of 2.4%. If we set aside the k = 1 case, the result from the pooled data regression yields some evidence that tradability reduces the degree of LOP deviations. The tradability effect, however, is quite small and likely to be non-monotonic. Overall, the results from (4) do not unequivocally support the notion of a significant tradability effect.

Given the generally weak effects of $\beta_{k,t}$'s, the α_t estimate is a good proxy for the "average" of LOP deviations. In this regard, we note that the α_t estimate evolves nonlinearly in Figure 1 – it drifts down in the 1980s, moves up in the 1990s, and shows a slight downward trend in the new millennium. In other words, the time profile of the average LOP deviation does not corroborate with the usual perception that markets are increasingly integrated over time because of increasing trade and improving telecommunication and transportation technologies. The next two subsections provide additional analyses to shed some light on the dynamics of LOP deviations.

4.2 Trend Behavior

The trend behavior of the product-by-product price dispersion is of both academic and policy interests. A severe violation of the LOP is indicative of market imperfection and a source of welfare loss (Engel and Rogers, 2001). Anecdotal evidence based on increasing global trade volume, decreasing trade barriers, and improving transportation technology suggests deviations from the LOP should shrink over time. The strongest evidence for convergence is, perhaps, provided by Goldberg and Verboven (2005) who document price convergence in the European car market during the integration process.The empirical evidence, however, is not uniformly supportive of the convergence view. For instance, Bergin and Glick (2007), Engel and Rogers (2004), and Rogoff, Froot, and Kim (2001) suggest international price dispersion does not decline monotonically.

For the Japanese price data, Figure 1 shows that the deviation from the LOP evolves in a nonlinear manner over time. Thus, to obtain some preliminary inferences about the nonlinear behavior of intra-Japan LOP deviations, we consider the following regression equations:

$$|\,\overline{p}\,|_{i(k),.,t} = \alpha_{i(k)} + \beta^{L}_{i(k)} t + \varepsilon_{i(k),t}\,, \qquad (5)$$

$$|\,\overline{p}\,|_{i(k),.,t} = \alpha_{i(k)} + \beta^{L}_{i(k)} t + \beta^{Q}_{i(k)} t^2 + \varepsilon_{i(k),t}\,, \qquad (6)$$

and

$$|\,\overline{p}\,|_{i(k),.,t} = \alpha_{i(k)} + \beta^{L}_{i(k)} t + \beta^{Q}_{i(k)} t^2 + \beta^{C}_{i(k)} t^3 + \varepsilon_{i(k),t}\,. \qquad (7)$$

The three equations explore the possibility of linear, quadratic, and cubic trends in deviations from the LOP. The quadratic trend specification (6) is motivated by the U-shape dispersion pattern displayed by international prices (Bergin and Glick, 2007; Engel and Rogers, 2004). The cubic trend in (7) is included to capture the nonlinear behavioral pattern revealed in Figure 1. The results of estimating equations (5) to (7) are reported in Table 5.

The case of a linear trend is presented in Panel A of the Table. Columns 2 to 4 give the numbers of products that exhibit zero, negative, and positive trends, respectively. The products exhibiting a positive time trend outnumber those with a negative time trend roughly by a ratio of 2 to 1 (55 to 27). For individual tradability categories, the $k = 2$ group is the only one that has equal numbers of positive and negative trend estimates. There are only four products; two belong to the $k = 4$ group and two to the $k = 2$ group, display an insignificant time trend. In sum, over one-half of the products in the sample have experienced an increasing deviation from the LOP. The result is at odds with the common perception that prices tend to converge over time but is in line with studies that do not find price convergence (Rogoff, Froot, and Kim, 2001).

The entries under Column 5 in Table 5 are the time trend estimates obtained by pooling data within the corresponding tradability categories. Fixed effects are included to allow for product-specific effects in estimating the trend coefficient. All the time trend estimates, with the exception of the $k = 2$ category, are significantly positive and, thus, indicate that on average the LOP deviation has a positive time trend – a result that is not in accord with the convergence hypothesis. We note that, by pooling the data across individual products, one may overlook the heterogeneous behavior even within a specific tradability category.

Again, with the exception of the $k = 2$ category, the trend estimate is increasing with the tradability. That is, the tradables are on average moving away from the LOP at a faster rate than the nontradables. The finding is puzzling. Compared with nontradables, prices of tradables are expected to converge at a faster rate (or not to diverge at a faster rate) with, for example, improving transportation technology and enhancing distribution system.

The numbers of products with zero, negative, and positive quadratic trends are presented in columns 2 to 4 of Panel B. The entries in square brackets are the numbers of linear trends. The presence of nonlinearity is quite pronounced. A negative quadratic trend is found in 30 products and a positive trend in 36 products. Note that a positive quadratic trend implies that the LOP deviation has a U-shape time profile while a negative quadratic trend implies an inverted U-shape time profile. The tradables, compared with nontradables, have a marginally higher proportion of products displaying a positive quadratic trend.

The average quadratic trend estimates obtained from pooled regressions do not reveal an unambiguous link between tradability and quadratic trend pattern (Column 6 in Table 5). The tradables as a group have a positive quadratic trend estimate and the nontradables have a negative one, but neither estimate is significant. For the individual tradability categories, the $k = 4$ and $k = 2$ categories have a negative quadratic trend estimate while the $k = 3$ and $k = 1$

categories have a positive one. Only the estimates for the two tradable categories are significant, but they are with opposing signs. Apparently, pooling data across all the products masks the individual nonlinear behavior and yields an insignificant quadratic trend estimates.

The presence of a quadratic trend changes the linear trend results. Compared with Panel A, Panel B reports a smaller number of significant positive linear trend estimates and a larger number of negative trend estimates, and these significant trends are distributed more evenly within individual tradability categories. Further, with the pooled data only the $k = 1$ and $k = 4$ categories in Panel B have a significant linear trend estimate. In both Panels A and B, however, the tradable $k = 4$ category's average linear trend estimate is larger than the nontradable $k = 1$ category's.

In a way, the results in Panel B offer a qualified support of the U-shape pattern reported in Bergin and Glick (2007). Specifically, our results reveal the presence of both U-shape and inverted U-shape patterns among individual products. Obviously, these two patterns have very different implications for price convergence behavior.

The trend estimates obtained from equation (7) are summarized in Panel C. The numbers of significant cubic trend estimates are listed under Columns 2 to 4 with the quadratic and linear trend estimates in round and square brackets, respectively. Of the 86 products, 44 have a significant negative cubic trend estimate and 21 have a positive one. With the exception of the $k = 2$ category, the cubic trend estimates from pooled regressions are significantly negative.[10]

Note that a negative cubic term implies that the time path of LOP deviations follows a decrease, increase, and then a decrease pattern. These pooled cubic trend estimates are broadly in line with the nonlinear pattern of the average of LOP deviations revealed in Figure 1. It is interesting to note that tradables, compared with nontradables, tend to have a faster convergence to the LOP as indicated by the magnitude of its cubic trend estimate – an inference that is different from those from Panels A and B.

The contingency table analysis, again, was used to determine whether the distribution of positive versus negative trends depends on tradability. Under the tradables-nontradables dichotomy, the χ^2 test statistics for the linear, quadratic, and cubic trends in (7) are, respectively, 0.14, 1.79, and 1.99. These statistics offer no significant evidence that tradability

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[10] In fact, the $k = 2$ category is the only category that has insignificant linear, quadratic, and cubic trend estimates.

affects the distribution of positive and negative trends. The results for the finer classification of four tradability groups yield the same no-effect inference with the χ^2 test statistics of 1.50 (linear), 6.11 (quadratic), and 6.85 (cubic).

In sum, it is important to account for nonlinearity in examining the evolution of deviations from the LOP. The Japanese data highlight the presence of a wide variation of convergence behaviors among individual products. If only a linear trend is considered, the result is indicative of increasing deviation from LOP. The quadratic and cubic trend results, however, offer a different prospective on LOP convergence. Indeed, so far, the cubic trend estimates offer the strongest evidence that tradability alleviates deviations from the LOP.

4.3 Economic Determinants

The nonlinear trend behavior of LOP deviation is quite prevalent and diverse among the Japanese retail price data. In this subsection, we turn to the economic factors underlying the evolution of the product-specific LOP deviation. Recall that $|\overline{p}|_{i(k),.,t}$, our measure of LOP deviations, is a mean absolute value that is related to a product's price dispersion. Thus, we can appeal to the theory of price behavior that studies price dispersion for its economic determinants.

Some theories of price behavior suggest that inflation is a potential determinant of price dispersion. For instance, models based on imperfect information, consumer search costs, and menu costs all suggest a link between inflation and price dispersion.[11] In particular, under imperfect information and costly search, one can construct a model in which dispersion of prices exists in equilibrium (Lach, 2002; Lach and Tsiddon, 1992; Van Hoomissen, 1988).

Motivated by theoretical predictions, we consider the product-specific inflation given by

$$\pi_{i(k),.,t} = \Sigma_{j=1}^{N} (\ln P_{i(k),j,t} - \ln P_{i(k),j,t-1}) / N \ . \qquad (8)$$

An issue to address is the functional form of $\pi_{i(k),.,t}$ used in the regression analysis. Based on the discussion in the literature, we experimented with $\pi_{i(k),.,t}$ itself, its absolute value $|\pi|_{i(k),.,t}$, and its positive and negative components ($\pi^{+}_{i(k),.,t}$ and $\pi^{-}_{i(k),.,t}$). It turns out that the best overall fit

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[11] Fischer (1981) discusses alternative views on the link between inflation and price dispersion. For example, Lucas (1973) and Barro (1976) illustrate the implication of imperfect information, Sheshinski and Weiss (1977) and Ball and Mankiw (1995) show the effect of menu costs, and Benabou (1988) discusses the implications of search costs.

is obtained by the asymmetric version that separates the positive and negative inflation effects. Thus, for brevity, we present the results from these two regression equations:[12]

$$|\,\overline{p}\,|_{i(k),.,t} = \alpha_i + \lambda_i^+ \pi_{i(k),.,t}^+ + \lambda_i^- \pi_{i(k),.,t}^- + \varepsilon_{i(k),t} \qquad (9)$$

and

$$|\,\overline{p}\,|_{i(k),.,t} = \alpha_i + \beta_{i(k)}^L t + \beta_{i(k)}^Q t^2 + \beta_{i(k)}^C t^3 + \lambda_i^+ \pi_{i(k),.,t}^+ + \lambda_i^+ \pi_{i(k),.,t}^- + \varepsilon_{i(k),t}\,. \qquad (10)$$

The dependent variable $|\,\overline{p}\,|_{i(k),.,t}$ defined by equation (3) is the product-specific average of absolute LOP deviations and a measure of price dispersion. The product-by-product estimation results are summarized in Table 6. Specifically, for each tradability group, we report the averages of coefficient estimates from individual products within the group. Underneath each average estimate, we include the corresponding standard deviation in parentheses and the number of products yielding significant coefficient estimates in square brackets.

Among the 86 product-specific LOP deviation series, 43 are significantly affected by positive inflation and 50 by negative inflation (Column 2 of Table 6). The signs of the coefficient estimates suggest that price changes in either directions lead to an increase in deviations from the LOP; that is both inflation and deflation induce price dispersion across cities. On average, the negative inflation has a larger impact on price dispersion than the positive one. In fact, the null hypothesis of a symmetric inflation effect (i.e. $\lambda_i^+ + \lambda_i^- = 0$) is rejected for 46 products. The general pattern of positive and negative inflation effects is shared by products in individual tradability groups (Columns 3 to 6).

The last five columns of Table 6 present the combined effects of the trends and the inflation variables. The inclusion of the trend terms reduces the frequency of having a significant negative inflation effect and shrinks the difference between the positive and negative inflation effects. Nonetheless, there are still substantial asymmetric inflation effects.

The trend behavior appears not being substantially affected by the presence of the inflation variables. The numbers of significant cubic, quadratic, and linear trend estimates in these columns are quite comparable with those in Table 5. Apparently, the component of LOP deviations explained by product-specific inflation is different from that by these trend variables.

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[12] The results based on alternative specifications of the inflation variables are available from the authors. Also, results based on the variance of deviations, instead of the average of absolute deviations are essentially the same as those reported in the text.

The observed asymmetry effects of positive and negative inflation warrant some discussion. Theoretically, inflation and price dispersion can interact in various ways; see footnote 11. Japan's recent inflation and deflation experiences, which are not commonly found in other major developed countries, represent a good case study of the inflation effect. Since the second half of the 1990s, Japan has experienced a prolonged period of deflation and economic stagnation. The Bank of Japan, being constrained by the zero interest rate, has employed the quantity-based measure to implement strong expansionary policy and used announcements to calm market uncertainty. If the Bank of Japan actions do not reduce the uncertainty in the presence of deflation, then the downward price movement can lead to large price dispersion.

As an alternative look at the data, we also pooled the observations across individual products and estimated the panel versions of (9) and (10). Product-specific fixed effects were included. It turns out that the pooled regression results on the asymmetric inflation effects and the trend behavior are qualitatively similar to those in Table 6. Thus, for brevity, these results are not reported, but are available upon request.

In addition to the effect of a product's own inflation, some theories emphasize the role of aggregate shocks such as monetary shocks and supply shocks in generating price dispersion. To account for these effects, we modify (9) and (10) and consider the extended specifications:

$$|\bar{p}|_{i(k),.,t} = \alpha_i + \lambda_i^+ \pi_{i(k),.,t}^+ + \lambda_i^- \pi_{i(k),.,t}^- + \phi_i \pi_t + \gamma_i m_t + \varphi_i y_t + \varepsilon_{i(k),t}\,, \tag{11}$$

and

$$|\bar{p}|_{i(k),.,t} = \alpha_i + \beta_{i(k)}^L t + \beta_{i(k)}^Q t^2 + \beta_{i(k)}^C t^3 + \lambda_i^+ \pi_{i(k),.,t}^+ + \lambda_i^- \pi_{i(k),.,t}^- + \phi_i \pi_t + \gamma_i m_t + \varphi_i y_t + \varepsilon_{i(k),t}\,. \tag{12}$$

The three added variables are a) the aggregate consumer price inflation, π_t, b) the money volatility, m_t, and c) the output volatility, y_t. The volatility variables are the conditional variances obtained from fitting time series models that allow for autoregressive conditional heteroscedasticity to the Japanese data on M2+CD and industrial production.[13]

The results of estimating (11) and (12) are presented in Table 7. The product-specific asymmetric inflation effects are quite comparable to those in Table 6. The three added aggregate

[13] Based on the Schwartz-Bayesian information criterion and diagnostic checking results, an AR(12)-ARCH(1) model was used for both the M2+CD and industrial production series.

variables have only limited effects on deviations from the LOP. In the presence of trend variables, only 13 products have a significant aggregate inflation effect, 6 have a significant output volatility effect, and 22 have a significant money volatility effect. Indeed, the coefficient estimates of these three aggregate variables exhibit high variability across products, and their effects do not appear uniformly important. The results for (12) indicate that the inclusion of the three aggregate variables does not have a material impact on the trend estimates.

The results from the panel versions of (11) and (12) are quite similar to those in Table 7 – none of the three added aggregate variables is significant and the inclusion of these variables has very limited implication for the asymmetric inflation effect. Further, replacing money volatility by aggregate inflation volatility in (11) and (12) gives qualitatively similar estimation results. To conserve space, these results are not reported but are available from the authors. Taking all the evidence together, we infer that the effects of these three aggregate variables on price dispersion are quite weak.

Recently, Bergin and Glick (2007) find that oil prices, which are viewed as a proxy for transportation costs, help explain the nonlinear behavior of international price dispersion. Thus we explored the possible oil price effect. First, we included the monthly Japanese gasoline retail price series in (11) and (12). The gasoline price series is only available from April 1987 onward. Then, we considered crude oil import prices that are available for the entire sample period but only at the annual frequency.[14] Neither the product-by-product nor panel regressions yield a significant gasoline/crude oil price effect. That is, the intra-Japan price behavior is not affected by the oil price and the related gasoline price data.

5. Concluding Remarks

We study the deviations from the LOP in Japan using 25 years of monthly data on individual retail prices collected for 86 narrowly defined consumer products in 67 cities. The intra-Japan comparison eliminates the extraneous effects of, for example, exchange rate uncertainty and dis-similar national policies on the LOP deviation dynamics. Our empirical exercise reveals some interesting properties of LOP deviations in Japan. All in all, these

[14] The gasoline retail prices are from http://oil-info.ieej.or.jp/. The crude oil import data are from the *OECD Factbook 2007: Economic, Environmental and Social Statistics*. All these results are not reported to save space but are available from the authors.

product-specific empirical results raise some issues with the LOP doctrine and offer some hints on what determines a product's (average) deviation from the parity condition.

An issue that warrants further investigation is whether the reported properties of LOP deviations are unique to the second largest economy in the world or they bear some relevance for the general LOP discussion. For instance, our exercise offers some mixed results on the role of tradability. The arbitrage argument, for example, implies that tradability facilitates the LOP convergence. While there is evidence that tradability affects the distribution of LOP deviations, the view that tradability enhances price convergence does not receive strong support from the unit root test results and the sum of autoregressive coefficient estimates. These findings are in contrast with the tradability-enhances-convergence result from international price data (Crucini and Shintani, forthcoming). At the same time, they are not totally contradictory to the result of the US traded goods have a larger variance of LOP deviations (Engel and Rogers, 2001).[15]

Further, it is found that the aggregation of these Japanese LOP deviation series does not increase persistence – a result that does not corroborate the common perception that aggregation leads to high real exchange rate persistence.

The complexity of the evolution of LOP deviations and the related market integration process is reflected by the presence of linear, quadratic, and cubic trends. The nonlinear behavior of the Japanese product-specific LOP deviations appears more complicated than the one reported by studies including Bergin and Glick (2007) and Rogoff, Froot, and Kim (2001). While we identified a few economic variables that affect LOP deviations in Japan, these economic variables do not fully account for the nonlinear trend behavior. The oil price effect that helps explain nonlinearity in international price data do not show up significant for the Japanese LOP deviations. Also, the average deviation from the LOP displayed by these Japanese products is in the order of 10%, which is higher that a few percentage points reported for products in EU countries.

Arguably, the ultimate forces driving the evolution of LOP deviations are not yet completely understood. It is too early to say whether these results should be considered as empirical facts in general or something specific to the Japanese economy. One area that is worth

[15] These results are not likely to be driven by our tradability classification scheme. If we followed the usual approach and labeled only services related products (that is, those under our $k = 1$ category) the nontradables, the inferences about the tradability effect will not change in a

exploring is the microstructure of the Japanese retail market and its implications for the observed deviations from the LOP. It is known that the Japanese retail market and the underlying distribution network are different from those in, say, the US. Even though our analysis indicates that neither crude oil nor gasoline retail prices help explain LOP deviations, it is conceived that individual products can display different patterns of LOP deviations if they face different transportation and distribution cost structures.[16] At this moment, we do not have time series data of these product-specific costs.

qualitative manner.

[16] For example, Crucini and Shintani (forthcoming) use the disaggregated US NIPA data and input-output data to infer distribution margins and MacDonald and Ricci (2005) examine the impact of the distribution sector on real exchange rate dynamics and convergence.

Appendix

Table A.1 List of Cities

ID	Cities	Prefecture
1	Sapporo	Hokkaido
2	Hakodate	
3	Asahikawa	
4	Aomori	Aomori
5	Morioka	Iwate
6	Sendai	Miyagi
7	Akita	Akita
8	Yamagata	Yamagata
9	Fukushima	Fukushima
10	Koriyama	
11	Mito	Ibaraki
12	Utsunomiya	Tochigi
13	Maebashi	Gumma
14	Saitama	Saitama
15	Kawaguchi	
16	Tokorozawa	
17	Chiba	Chiba
18	Ku-area of Tokyo	Tokyo
19	Fuchu	
20	Yokohama	Kanagawa
21	Kawasaki	
22	Yokosuka	
23	Atsugi	
24	Niigata	Niigata
25	Nagaoka	
26	Toyama	Toyama
27	Kanazawa	Ishikawa
28	Fukui	Fukui
29	Kofu	Yamanashi
30	Nagano	Nagano
31	Matsumoto	
32	Gifu	Gifu
33	Shizuoka	Shizuoka
34	Hamamatsu	
35	Nagoya	Aichi
36	Kasugai	
37	Tsu	Mie
38	Otsu	Shiga
39	Kyoto	Kyoto

ID	Cities	Prefecture
40	Osaka	Osaka
41	Hirakata	
42	Higashi-osaka	
43	Kobe	Hyogo
44	Himeji	
45	Nishinomiya	
46	Itami	
47	Nara	Nara
48	Wakayama	Wakayama
49	Tottori	Tottori
50	Matsue	Shimane
51	Okayama	Okayama
52	Hiroshima	Hiroshima
53	Yamaguchi	Yamaguchi
54	Tokushima	Tokushima
55	Takamatsu	Kagawa
56	Matsuyama	Ehime
57	Kochi	Kochi
58	Fukuoka	Fukuoka
59	Kitakyushu	
60	Saga	Saga
61	Nagasaki	Nagasaki
62	Sasebo	
63	Kumamoto	Kumamoto
64	Oita	Oita
65	Miyazaki	Miyazaki
66	Kagoshima	Kagoshima
67	Naha	Okinawa

Notes: Ku-area of Tokyo refers to the Tokyo metropolitan area that consists of its twenty-three districts.

Table A.2 List of products

Category	Description	id	k
Manufacturing products	Rice bowls	4301	4
	Dishes	4302	4
	Glasses	4322	4
	Scrubbing brushes	4342	4
	Detergent, laundry	4441	4
	Men's business shirts (short sleeves)	5301	4
	Men's briefs	5311	4
	Neckties	5511	4
	Men's shoes (leather)	5601	4
	Women's shoes (leather)	5611	4
	Women's sandals	5671	4
	Medicines for cold (antipyretic & analgesic)	6001	4
	Vitamin preparations (multivitamins)	6021	4
	Dermal medicines	6051	4
	Thermometers	6131	4
	Bicycles	7201	4
	Notebooks	9121	4
	Toothbrushes	9611	4
	Shampoo	9622	4
	Handbags	9721	4
	Handkerchiefs	9761	4
Storable foods and drinks	Glutinous rice	1011	3
	Wheat flour	1071	3
	"Niboshi", dried small sardines	1146	3
	Dried laver	1461	3
	"Wakame", seaweed	1462	3
	Dried tangle	1463	3
	"Umeboshi", pickled plums	1482	3
	Pickled radishes	1483	3
	Sliced vegetables pickled in soy sauce	1484	3
	Tangle prepared in soy sauce	1485	3
	Soybean paste	1631	3
	Sugar	1632	3
	"Shio senbei", Japanese rice crackers	1741	3
	"Kawara senbei", Japanese wheat crackers	1742	3
	Peanuts	1772	3
	Green tea ("Bancha")	1901	3
	Green tea ("Sencha")	1902	3
	Sake (high quality)	2002	3

Category	Description	id	k
Meat, fresh produces, dairy products, and other perishable food items	White bread	1021	2
	Octopus	1113	2
	Salted salmon	1141	2
	"Chikuwa", baked fish-paste bars	1152	2
	Beef (loin)	1201	2
	Pork (loin)	1211	2
	Chicken	1221	2
	Hen eggs	1341	2
	Cabbage	1401	2
	Chinese cabbage	1403	2
	Welsh onions	1405	2
	Lettuce	1406	2
	Sweet potatoes	1411	2
	White potatoes	1412	2
	Radishes	1414	2
	Carrots	1415	2
	Burdocks	1416	2
	Onions	1417	2
	Pumpkins	1433	2
	Cucumbers	1434	2
	Eggplants	1435	2
	Tomatoes	1436	2
	Green peppers	1437	2
	Bean curd	1471	2
	Fried bean curd	1472	2
	"Natto", fermented soybeans	1473	2
	"Konnyaku", devil's-tongue jelly	1481	2
	Bananas	1581	2
	Salad	1811	2
	Croquettes	1821	2
Services and other non-tradable items	Japanese noodles	2101	1
	Chinese noodles	2102	1
	Chicken & eggs on rice	2131	1
	Curry & rice	2133	1
	Coffee (eating out)	2162	1
	Beer (eating out)	2171	1
	House rent (private)	3001	1
	House rent (public) (average)	3010	1
	"Tatami", reupholstering	3151	1
	Sheet-glass replacement	3161	1
	"Fusuma", sliding doors reupholstering	3171	1
	Kerosene	3701	1
	Taxi fares (first fares)	7061	1
	Taxi fares (each additional distance)	7064	1
	P.T.A. membership fees (elementary school)	8001	1
	Men's haircut charges	9511	1
	Permanent wave charges	9521	1

The Kolmogorov-Smirnov Test

Let $F(p_{i(k),t})$ and $G(p_{i*(k*),t})$ denote, respectively, the density functions of the unknown distributions of LOP deviations of products *i* and *i** at time *t*. Using the observed LOP deviations { $p_{i(k),j,t}$; *j* = 1, …, *N*} and { $p_{i^*(k^*),j,t}$; *j* = 1, …, *N*}, we calculate the corresponding empirical density functions and denote them by $\widetilde{F}(p_{i(k),t})$ and $\widetilde{G}(p_{i*(k*),t})$, respectively. Then, the sample statistic, *D*, can be used to test for the homogeneity between $F(p_{i(k),t})$ and $G(p_{i*(k*),t})$, where

$$D = \sup | \widetilde{F}(p_{i(k),t}) - \widetilde{G}(p_{i*(k*),t}) | .$$

Specifically, the null hypothesis that products *i* and *i** share the same distribution of LOP deviations will be rejected when

$$\sqrt{\frac{N}{2}} D \geq c$$

where *N* is the number of observations (i.e. the number of cities) for each product and *c* is the critical value corresponding to a pre-selected level of significance. For our exercise, we set c=1.36 to adopt the 5 % level of significance.

Similarly, the distributional equality of LOP deviations of product *i* at two different points in time, *t* and *t**, can be tested by applying the same procedure to the empirical distributions $\widetilde{F}(p_{i(k),t})$ and $\widetilde{G}(p_{i(k),t*})$.

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Table 1. Descriptive statistics of Deviations from the LOP

	Mean absolute value	Variance	Skewness	Kurtosis	Number of observations
All	0.131	0.035	-0.153	4.155	1682504
Tradables	0.126	0.035	-0.220	4.655	762996
Nontradables	0.136	0.036	-0.100	3.764	919508
$k = 4$	0.118	0.030	-0.001	5.344	410844
$k = 3$	0.135	0.040	-0.384	3.946	352152
$k = 2$	0.144	0.040	-0.191	3.624	586920
$k = 1$	0.122	0.029	0.158	3.675	332588
Administrated	0.116	0.029	0.754	4.211	78256
Non-Administrated	0.124	0.029	-0.026	3.509	254332

Notes: The Table presents the sample statistics of Law of One Price (LOP) deviations for products under the specified tradability categories. See the text for the definitions of the deviation from the LOP variable and the tradability categories.

Table 2. The Kolmogorov-Smirnov Test Results for the Distributional Homogeneity of LOP Deviations

	1981	1991	2001	2004
A. Tradables/Nontradables				
Both are tradables	66.65	62.30	54.03	52.03
Both are nontradables	40.47	29.74	33.45	31.70
B. Tradability Index				
(*k*, *k**)=(4, 4)	73.96	74.52	63.65	60.63
(*k*, *k**)=(3, 3)	56.86	49.02	43.57	43.19
(*k*, *k**)=(2, 2)	31.95	21.16	25.26	23.87
(*k*, *k**)=(1, 1)	47.54	39.76	44.30	43.32
C. Contingency Table Test	138.70**	178.17**	70.55**	52.42**

Notes: The rejection frequencies in percentage terms of the Kolmogorov-Smironov test based on the 95% level critical value are reported for the corresponding product-pairs. The figures in Panel C are χ^2 statistics for the null hypothesis that the rejection frequency is independent of the pairing scheme based on the tradables and nontradables classifications. "**" indicates significance at the 1% level.

Table 3. The Kolmogorov-Smirnov Test Results for the Time Variability of LOP Deviations

	Reject	Not reject	Total	Rejection rate (%)
A. 1981 versus 2001				
Tradables	173	295	468	36.96
Nontradables	28	536	564	4.96
$k = 4$	140	112	252	55.55
$k = 3$	33	183	216	15.27
$k = 2$	13	347	360	3.61
$k = 1$	15	189	204	7.35
Total	201	831	1032	19.47
B. 1981 versus 1991				
Tradables	150	306	468	32.26
Nontradables	24	552	564	4.07
$k = 4$	131	121	252	51.98
$k = 3$	20	185	216	9.25
$k = 2$	5	355	360	1.38
$k = 1$	18	197	204	8.82
Total	174	858	1032	16.86
C. 1991 versus 2001				
Tradables	127	341	468	27.13
Nontradables	14	550	564	2.48
$k = 4$	109	143	252	43.25
$k = 3$	18	198	216	8.33
$k = 2$	2	358	360	0.55
$k = 1$	12	192	204	5.88
Total	141	891	1032	13.66

Notes: For each product, its monthly distributions of the LOP deviations in a given year are compared with those in another year. Each year-pair comparison yields 1032 (=86x12 months) test statistics. The χ^2 statistics for independence between the Kolmogorov-Smirnov test results and tradables and nontradables (k=1~4) product categories are 167.00, 149.84, and 131.79 (288.93, 301.68, and 256.26) for panels A, B and C, respectively. These statistics are all significant at the 1 % level; indicating that the rejection rate depends on tradability.

Table 4. Unit Root Test Results and Persistence Estimates

	Reject	Not reject	Rejection rate (%)	Persistence
A. Tradables/Nontradables				
Tradables	1345	1268	51.47	0.927
Nontradables	1944	1205	61.73	0.819
B. Tradability index				
k=4	674	733	47.90	0.925
k=3	671	535	55.63	0.929
k=2	1410	600	70.14	0.750
k=1	534	605	46.88	0.941
Total	3289	2473	57.08	0.868

Notes: The results of applying the ADF-GLS test with a constant and a time trend to country-and-product-specific LOP deviation series are presented. Finite sample critical value is used to assess statistical significance at the 10 percent level (Cheung and Lai, 1995). "Reject" and "Not reject" columns give the numbers of rejection and non-rejection cases. The percentages of cases rejecting the unit root hypothesis are given in the column labeled "Rejection rate." The entries under the "Persistence" column are averages of the sum of the AR(q) coefficient estimates, where the optimal lag q is determined by the Schwartz-Bayesian information criterion, across the products within the specific tradability categories. The χ^2 test statistics reject the null hypothesis of independence between unit root test results and tradability classifications at the 1 % level of significance. Specifically, the test statistics are, respectively, 341.06 and 225.68 for results in Panels A and B.

Table 5. Trend Behavior of LOP Deviations

	Number of products with trends			Linear trend	Quadratic trend	Cubic trend
	Zero trend	Negative trend	Positive trend	($x10^4$)	($x10^7$)	($x10^8$)
A. Linear trend						
Tradable	2	9	28	1.018**		
Nontradable	2	18	27	.153**		
$k = 4$	2	4	15	1.073**		
$k = 3$	0	5	13	.954**		
$k = 2$	2	14	14	-.081*		
$k = 1$	0	4	13	.568**		
Total	4	27	55	.545**		
B. Quadratic trend						
Tradable	4 [4]	13 [17]	22 [18]	1.007**	.038	
Nontradable	16 [6]	17 [21]	14 [20]	.264*	-.381	
$k = 4$	1 [2]	9 [8]	11 [11]	1.720**	-2.214**	
$k = 3$	3 [2]	4 [9]	11 [7]	.175	2.668**	
$k = 2$	12 [5]	10 [14]	8 [11]	.164	-.844	
$k = 1$	4 [1]	7 [7]	6 [9]	.441*	.434	
Total	20 [10]	30 [38]	36 [38]	.601**	-.190	
C. Cubic trend						
Tradable	6 (5) [6]	25 (8) [22]	8 (26) [11]	-3.241**	36.350**	-.829**
Nontradable	15 (19) [18]	19(11) [18]	13(17)[11]	-.443	5.673**	-.138**
$k = 4$	1 (2) [5]	15 (4) [11]	5 (15) [5]	-4.342**	49.601**	-1.183**
$k = 3$	5 (3) [1]	10 (4) [11]	3 (11) [6]	-1.956**	20.891**	-.416**
$k = 2$	15 (16) [18]	6 (8) [6]	9 (6) [6]	.355	-2.477	.037
$k = 1$	0 (3) [0]	13 (3) [12]	4 (11) [5]	-1.853**	20.057**	-.447**
Total	21 (24) [24]	44(19)[40]	21(43)[22]	-1.712**	19.585**	-.451**

Notes: Panels A, B, and C, respectively summarize the linear, quadratic, and cubic trend estimation results. The entries in column 2 to 4 indicate the numbers of products exhibiting zero, negative, and positive trends. In Panel B, the numbers of linear trend estimates are given in square brackets. In Panel C, the numbers of quadratic (linear) trend estimates are given in round (square) brackets. **, *, and † indicate statistical significance at 1, 5, and 10% levels. The linear, quadratic, and cubic trend coefficients are scaled by the factors 10^4, 10^7, and 10^8, respectively.

Table 6. LOP Deviations and Asymmetric Inflation Effects

	Equation (9) - Without Trends					Equation (10) - With trends				
	All	*k*=1	*k*=2	*k*=3	*k*=4	All	*k*=1	*k*=2	*k*=3	*k*=4
A. Inflation effects										
+ Inflation	0.184	-0.047	-0.039	0.377	0.525	0.151	0.147	0.042	0.226	0.246
	(0.526)	(0.565)	(0.218)	(0.351)	(0.685)	(0.274)	(0.222)	(0.194)	(0.226)	(0.385)
	[43]	[8]	[17]	[7]	[11]	[45]	[8]	[17]	[9]	[11]
- Inflation	-0.514	-0.108	-0.161	-0.647	-1.232	-0.169	-0.037	-0.104	-0.230	-0.316
	(1.098)	(0.951)	(0.583)	(0.860)	(1.547)	(0.311)	(0.310)	(0.187)	(0.260)	(0.423)
	[50]	[6]	[18]	[11]	[15]	[35]	[4]	[14]	[7]	[10]
Asym cases	46	8	21	6	11	38	5	17	7	9
B. Trend behavior										
+ Cubic						23	4	10	4	5
- Cubic						44	12	7	10	15
+ Quadratic						45	12	7	11	15
- Quadratic						22	3	11	4	4
+ Linear						21	5	6	6	4
- Linear						40	12	6	11	11
# Products	86	17	30	18	21	86	17	30	18	21

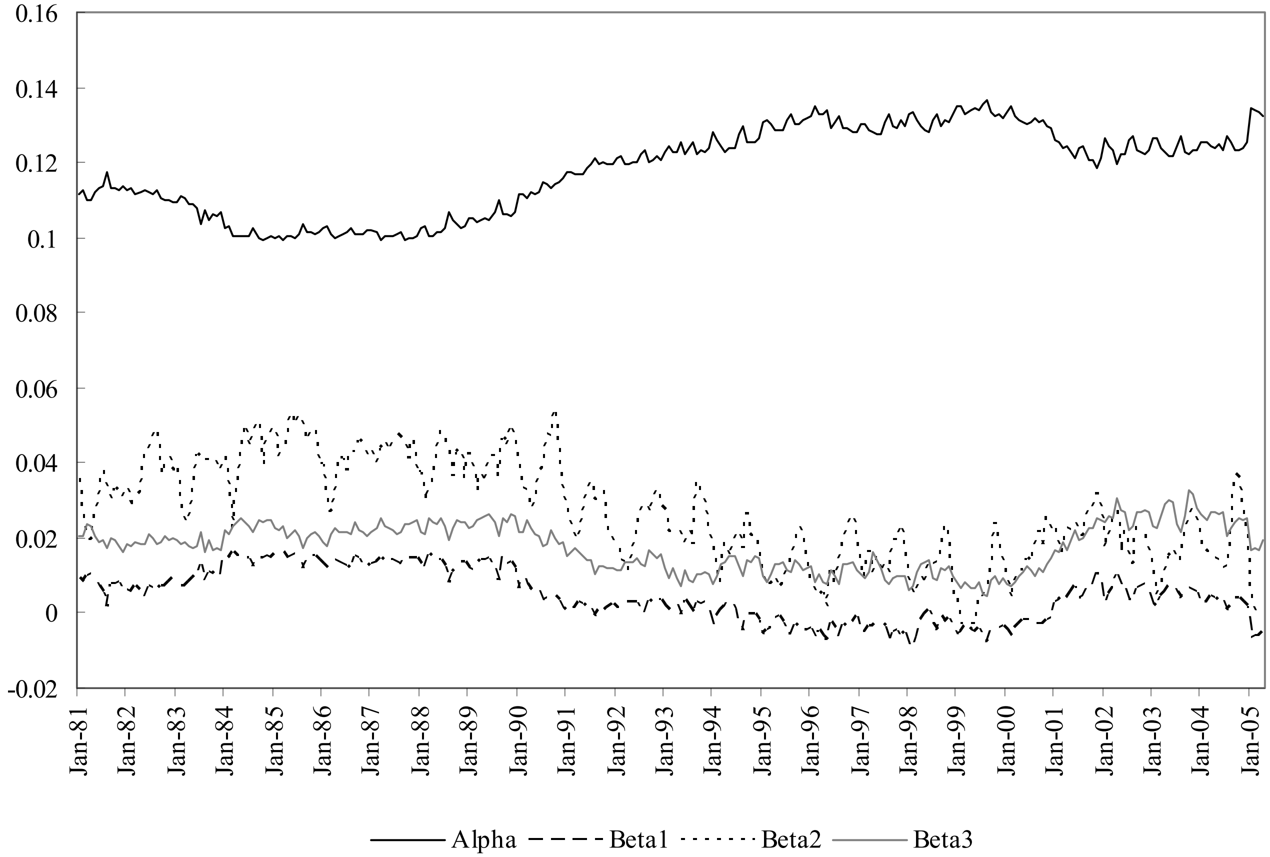
Notes: The product-by-product estimation results from equations (9) and (10) are presented. For each tradability category, the row labeled "+ Inflation" presents the average of the coefficient estimates of the positive inflation variable, their standard deviation in round brackets, and the number of significant estimates in square brackets. Similar information about the estimates of the negative inflation variable is provided in the "- Inflation" row. The row denoted "Asym cases" reports the number of products that reject the null hypothesis of symmetric inflation effects at the 5 percent level. The numbers of significant positive and negative cubic trend estimates obtained from (10) are presented in the rows labeled "+ Cubic" and "- Cubic." Similar information about quadratic and linear trend estimates are presented in rows labeled "+ Quadratic," "- Quadratic," "+Linear," and "- Linear." The numbers of products included in individual tradability categories are given in the "# Products" row.

Table 7. LOP Deviations, Asymmetric Inflation Effects, and Macro Variables

	Equation (11) - Without trends					Equation (12) - With trends				
	All	*k*=1	*k*=2	*k*=3	*k*=4	All	*k*=1	*k*=2	*k*=3	*k*=4
A. Inflation effects										
+ Inflation	0.182	-0.057	-0.041	0.389	0.519	0.148	0.144	0.038	0.225	0.242
	(0.531)	(0.589)	(0.215)	(0.347)	(0.684)	(0.271)	(0.224)	(0.192)	(0.225)	(0.379)
	[42]	[8]	[16]	[8]	[10]	[44]	[8]	[16]	[9]	[11]
- Inflation	-0.522	-0.125	-0.157	-0.665	-1.241	-0.166	-0.035	-0.104	-0.236	-0.300
	(1.113)	(0.994)	(0.578)	(0.849)	(1.576)	(0.316)	(0.336)	(0.191)	(0.250)	(0.429)
	[49]	[6]	[18]	[10]	[15]	[33]	[5]	[14]	[6]	[8]
Aggregate inflation	0.079	-0.000	0.322	-0.059	-0.086	0.059	-0.015	0.332	-0.034	-0.188
	(0.722)	(0.196)	(1.121)	(0.122)	(0.461)	(0.703)	(0.086)	(1.068)	(0.098)	(0.495)
	[9]	[1]	[6]	[0]	[2]	[13]	[0]	[8]	[0]	[5]
Output volatility	3.124	3.765	0.521	5.928	3.920	0.614	2.311	-0.283	2.262	-0.886
	(21.818)	(9.774)	(27.280)	(17.557)	(24.237)	(17.154)	(8.437)	(24.862)	(12.037)	(12.877)
	[2]	[0]	[2]	[0]	[0]	[6]	[0]	[2]	[3]	[1]
Money volatility	-2.467	-11.508	-2.868	-1.719	4.782	0.043	-3.442	-6.028	10.758	2.352
	(79.316)	(43.016)	(92.263)	(66.095)	(95.261)	(60.583)	(22.492)	(91.289)	(30.612)	(46.252)
	[17]	[2]	[6]	[5]	[4]	[22]	[4]	[8]	[5]	[5]
Asym cases	46	9	20	6	11	38	5	17	7	9
B. Trend behavior										
+ Cubic						22	4	10	3	5
- Cubic						44	12	7	10	15
+ Quadratic						45	12	7	11	15
- Quadratic						21	3	10	4	4
+ Linear						21	5	6	6	4
- Linear						40	12	6	11	11
# Products						86	17	30	18	21

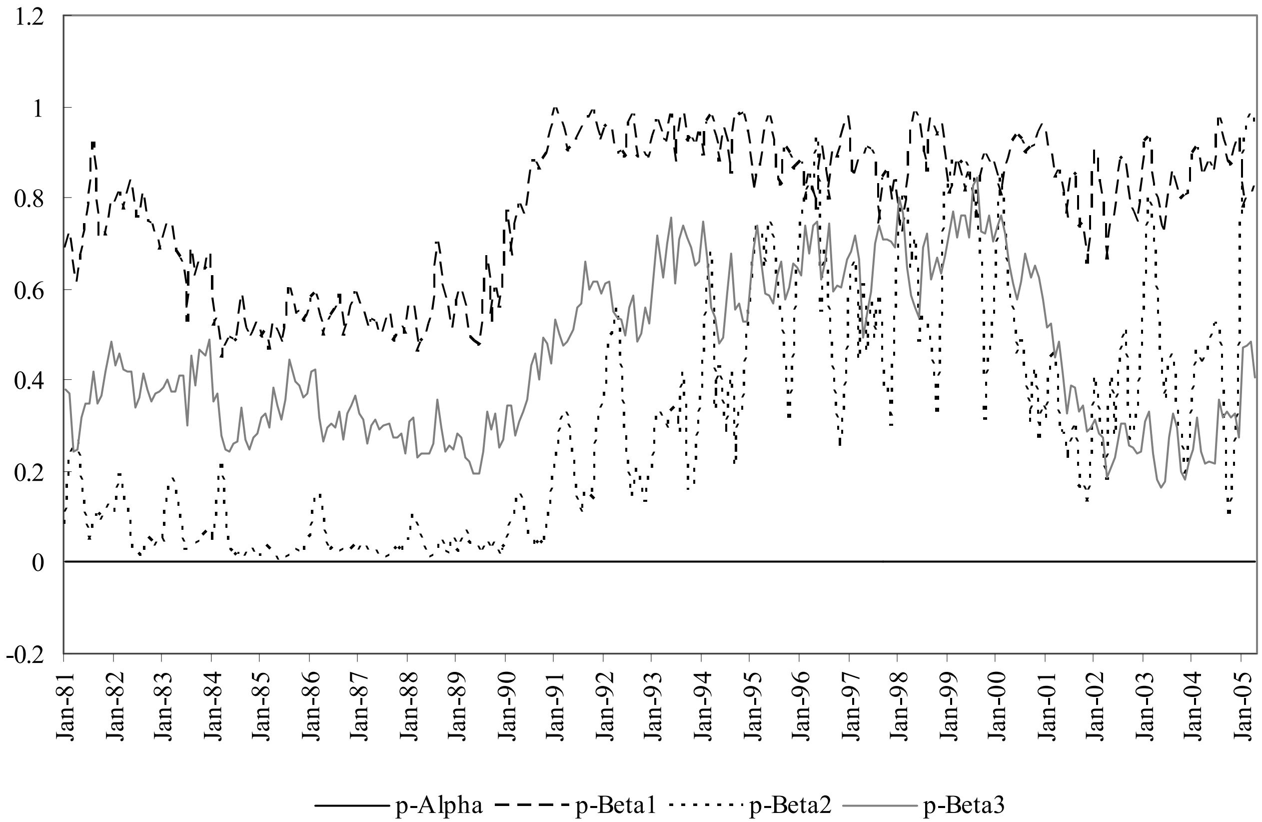
Notes: The product-by-product estimation results from equations (11) and (12) are presented. See the Notes to Table (6). The effects of the three macro variables are presented in the rows labeled "Aggregate inflation," "Output volatility," and "Money volatility" according to the format used to present the inflation effect.

Figure 1. Coefficient Estimates of the Tradability Index Dummy Variables



Notes: The figure displays the time profiles of the coefficient estimates obtained from estimating (4) – $|\,\overline{p}\,|_{i(k),.,t} = \alpha_t + \sum_{k=1}^{3} \beta_{k,t} D_{k(i)} + \varepsilon_{i,t}$, period by period.

Figure 2. Significance of the Tradability Index Dummy Coefficients



Notes: The figure displays the *p*-values of the coefficient estimates plotted in Figure 1.

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