How Fast Is Convergence to the Law of One Price? Very

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Abstract

In a highly disaggregated product-level sample of monthly frequency prices, the degree of persistence in cross-location price differentials is estimated. When location specific effects are accounted for in measuring price differentials, the median half-life of the conditional convergence to the Law of One Price is about four months. The degree of persistence is related to the mean and volatility in product price inflation. The equilibrium level of price differentials depends on the relative size of the location, but not on its geographical position.

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1 INTRODUCTION

Why do large and persistent deviations from the Purchasing Power Parity, the identity of price indices in two different locations expressed in the same currency exist? Similarly, in an international context, what explains the large and persistent movements in real exchange rates? One of the candidates in answering these long-standing, still unresolved puzzles in international macroeconomics is the failure of the Law of One Price (LOOP).

The LOOP is defined by the following observations. As consumers and firms can arbitrage away price differentials, prices of dis-aggregated goods and services measured in the same currency should be identical across geographic locations in the long run. That is, temporary price misalignments should quickly disappear over time. While the idea is strongly rooted in basic economic intuition, empirical analyses notoriously fail to establish support for it in the data. Price differentials tend to remain persistent over time, fading away only relatively slowly.

There exist several potential explanations for the failure in the law of one price. These primarily include transportation costs, different currencies with sticky prices, labor market segmentation, tariff and non-tariff barriers to trade, fluctuations in nominal exchange rates, productivity differentials, pricing to market, aggregation bias etc. It is unlikely that any of these factors in itself explains slow mean-reversion; instead, some combination of them could provide the answer. By studying the degree of persistence in relative price differentials across distinct locations within a single country, the approach this paper adopts testing the LOOP plays down the importance of many of the above explanations. In this sense, the estimated speed of convergence is expected to be faster here than in international price data.

The literature on convergence to the LOOP has primarily focused on cross-country, aggregate level price differentials. The consensus view in the international context on the estimated half-life of deviations from purchasing power parity has been three to five years; that is, convergence is present but it is very slow.[1] The current study differs from much of the LOOP literature in two fundamental dimensions. First, it examines price convergence among locations being geographically close to each other and sharing the same currency. Second, it uses a sample of highly dis-aggregated, product level prices of very narrowly defined homogenous items.

The rest of the paper is organized as follows. The microeconomic price data are described in Section 2. Section 3 takes up measurement and specification issues. The results are presented in Section 4. Section 5 briefly surveys some related results in the literature. Conclusions are offered in Section 6.

2 DATA

The empirical analysis builds on a data set of store level consumer prices recorded in Hungary. The sample is drawn from the larger sample of consumer prices collected at the monthly frequency for the computation of the CPI by the Central Statistical Office (CSO), Hungary, and

[1] See Rogoff (1996). For instance, Frankel (1990) estimated the half-life of PPP deviations to be 4.6 years, Wei and Parsley (1995) found it to be 4 to 5 years, Lothian and Taylor (1996) 4.7 years, Abuaf and Jorion (1990) 3.3 years.

consists of cross-sections of price observations of twenty homogenous consumer items, mostly specific food products and a few services. The particular products are selected from the full CPI database with an eye to obtaining very narrowly defined (according to size, branding, type and flavor etc.), continuously available items with negligible variation in non-price characteristics. Food items fall in the tradable (perishable or non-perishable) category, while services tend to be of the non-tradable type. The specific items are the following: pork chops, spare ribs, pork leg, beef round, beef shoulder, pork liver, italian sausage, boiling sausage, carp, curd, lard, fat bacon, smoked boiled bacon, flour, sugar, dry biscuits, tomato paste, vinegar, car driving school, movie ticket.

Table I lists the products together with the expenditure weight attached to them in the aggregate CPI, and their relative expenditure weight in the current sample. The table also reports the mean and standard deviation of product level monthly inflation. The standard deviation figures suggest that product-specific inflation rates tend to be extremely variable. They also indicate that monthly inflation rates substantially differ across items, their mean ranges from 1.19 to 2.82 percent, and their standard deviation from 1.64 to 8.06 percent.

The data set covers a period of 120 months, from 1992:1 until 2001:12, at the monthly frequency. In each month, there are 100-150 price observations (on average about 130) for each product. While stores in the sample are identified by their location, they are not longitudinally matched. Nonetheless, data collectors are formally instructed by the CSO to keep the set of stores unchanged as much as possible. In addition, the number of stores is relatively constant with an average standard deviation of less than 3 over time. Prices are recorded in 20 geographically dispersed locations including all the 19 counties in Hungary and the capital city, Budapest. Given its central economic and geographic importance in Hungary, Budapest is used as the benchmark city in much of the analysis. Table II shows the list of locations.

County-product-time specific mean prices are computed as the arithmetic average of price observations of the same item, in the same county, in the same month. The resulting balanced panel of 48,000 data points has three dimensions with 20 counties, 20 products and 120 months.

Despite the turbulent economic environment during economic transition, CPI inflation has been relatively moderate throughout the sample period. Month-to-month changes in the monthly aggregate CPI and its food component are plotted in Figure I. The graph shows that after an initial burst, inflation decelerated by 1994. After reaching its local minimum of about 15 percent on an annual basis, inflation dynamics eventually turned on an increasing path reaching its peak in early 1995. Starting during the second quarter of 1995 shortly after the announcement and implementation of a macroeconomic adjustment package in March 1995 and lasting through the rest of the sample period, a steady disinflationary trend took effect.

3 MEASUREMENT AND SPECIFICATION

The product-specific price differential between two counties is defined as the log-difference between the benchmark and actual price levels

$$Q_{ij,t}^{k} = \ln(P_{i,t}^{k} / P_{j,t}^{k}),$$

where $P_{j,t}^{k}$ is the price of item k in county j in month t. Correspondingly, $P_{i,t}^{k}$ is the price of item k in month t observed in the benchmark location i, Budapest.

Persistent income differences, local non-tradable factors of production, costs of transportation and other potentially time-invariant barriers of trade may create a constant wedge among retail prices at different locations. In this case, forces of arbitrage may never fully drive price differentials to zero; instead, they are more likely to approach a common, potentially non-zero mean. To account for time-invariant, location-specific effects in price differentials, it is useful to make a transformation of price differentials, and define their mean-difference as

$$Y_{ij,t}^{k} = Q_{ij,t}^{k} - \frac{1}{T}\sum_{t=1}^{T} Q_{ij,t}^{k} .$$

where the number of time periods is $T = 120$.[2]

The fundamental objective of the analysis is to characterize the degree of persistence in *intra*-country price differentials, after taking into account non-vanishing price differences across locations. To do so, a series of panel unit tests are employed using the procedure developed by Levin, Lin and Chu (2002).[3] The product-specific regression specified to estimate the speed of convergence is the following:

$$\Delta Y_{ij,t}^{k} = \beta_k Y_{ij,t-1}^{k} + \sum_{p=1}^{s(k)} \gamma_k^{p} \Delta Y_{ij,t-p}^{k} + \omega_{ij,t}^{k} .$$

The optimal lag structure in the regressions is determined by a series of product-county specific t-tests. As a result, the number of lags differs across counties. The parameter of primary interest in the specification is β_k, capturing the degree of persistence in price differentials. The null of non-stationarity in price differentials is the hypothesis of $\beta_k = 0$. The one-sided alternative is that the autoregressive coefficient is negative, $\beta_k < 0$. As demonstrated by Levin, Lin and Chu (2002), the resulting t-statistic on the autoregressive coefficient is distributed normally.

Given the estimated autoregressive coefficients, the implied half-life of deviations from the LOOP is calculated under the assumption that the price differential process is AR(1). In particular, for each product k, the half-life of deviations is defined as $h_k = \ln(0.5)/\ln(1+\beta_k)$. The main reason for neglecting higher order terms in the impulse response is that higher order terms tend to be insignificant. In addition, higher order lags differ across locations, making in turn difficult to characterize persistence at the product level.

[2] See Parsley and Wei (1996).

[3] The main advantage of panel tests over univariate ones is increased power. An alternative testing procedure that allows for individual heterogeneity in a panel model is developed by Im, Pesaran and Shin (2003).

4 RESULTS

The estimated autoregressive coefficients from the panel unit root test along with the corresponding *t*-statistics are reported in the first two columns of Table III. Comparisons with the critical values provided by Levin, Lin and Chu (2002) suggest that the null of unit root can be safely rejected for all items. The point estimates (one minus the estimate of the root) are significantly different from zero; indeed, the autoregressive parameters range from 0.73 to 0.94. The median value is 0.84. The corresponding estimates for the half-life of convergence to the relative LOOP are displayed in the last column in Table III. The results show that price differentials are fading away fairly fast, the estimated half-life is between 2.18 and 12.03 months, with a median value of 3.99 months. Price differentials disappear extremely fast, certainly faster than found anywhere else in previous studies.

It is instructive to examine how product characteristics are related to the degree of persistence in price differentials. First, price differentials of services appear to be particularly persistent, while adjustment in food prices (perishable or non-perishable) is faster. Prices of perishables adjust only slightly faster than prices of non-perishable; the average half-life of their adjustment is 4.29 months compared to the similar figure of 4.37 months for non-perishable ones. Moreover, the relatively slower adjustment of non-perishables appears to be due to one outlier item, tomato paste. Taking that item out of the sample, the sample average is reduced to 3.34 months. These results are puzzling to the extent that one would expect non-perishable items to be more easily transportable and thus having less persistent price differentials.

Second, the degree of persistence also appears to be related to trend inflation and volatility in product prices, as shown in Table I. In particular, the half-life of deviations from the LOOP and trend inflation are significantly positively correlated with a coefficient of 0.38. At the same time, the half-life of deviations is negatively correlated with the volatility measure with a coefficient of –0.18; though this coefficient is statistically not significant. Consistently with the two-sided (S,s) pricing model such as the one in Tsiddon (1993), these results suggest that higher and less variable inflation increases the probability of price adjustment, thus fastening the elimination of cross-location price differentials.

Next, to assess the robustness of the results, the panel unit root test is applied to price differentials *not* purged from product-location-specific components. The results in Table IV clearly show that the raw price differential series are more persistent than the demeaned ones. The autoregressive coefficients range from 0.83 to 0.99 with a median value of 0.94. Indeed, one of the products in the sample, movie price tickets series cannot be rejected to be non-stationary. The corresponding half-life of unconditional convergence is also higher with the largest value being 3.65 months and lowest value being 115.18 months. The median half-life is only 11.6 months. While service price differentials disappear only very slowly, the half-lives of deviations for perishable and non-perishable items are only 6.63 and 5.59 months, respectively.

Ultimately, the speed of adjustment to the LOOP is shaped by the size and the degree of coordination of pricing shock and by the magnitude of impediments to arbitrage and adjustment, including differences in the market size of and the geographical distance between locations. In order to learn about the nature of arbitrage costs, the following gravity equation is specified

$$Q_j = a + b * d_j + c * u_j + \varepsilon_j \,,$$

where Q_j is the county-specific mean price differential relative to the benchmark location, Budapest, obtained by averaging over all products k and months t in county j. d_j is the distance between the main city in district j and the benchmark location. The variable u_j is the number of people living in county j, proxying for market size in the county. The regression results displayed in Table V show that a higher distance from the benchmark location increases the mean price differential, though the relationship is statistically insignificant. At the same time, the population size of the county has a statistically significant negative impact on the mean price differential. This suggests that time-invariant price differentials tend to shrink with market size.[4]

5 RELATED LITERATURE

A number of studies have particularly close bearings on the current analysis. First, Parsley and Wei (1996) estimate the half-life of deviations of prices across U.S. cities. The data is at the quarterly frequency from the first quarter of 1975 to the fourth quarter of 1992, and consist of prices of 51 products observed in 48 locations. The products are divided into nonperishable, perishable and services categories. The main variable of interest is the log-difference in price levels, without demeaning between individual cities and the benchmark city, New Orleans. First, they reject the null hypothesis of random walk for most items. They conclude that the estimated median half-life for nonperishable goods is 5.28 quarters, for perishable goods 4.05 quarters, and for services 15.4 quarters. To test for non-linear effects, Parsley and Wei add a quadratic term as well, and they find that higher price differential is closed at a faster rate than a smaller price differential. Finally, they also analyze the dependence of the mean absolute deviation in and the variability of price-differentials on distance. They find positive association in both specifications, implying increasing costs to arbitrage as two cities being further apart from each other.

Building on the analysis of Parsley and Wei, Cecchetti, Nelson and Sonora (2001) study price convergence in a 78 years long panel of annual price indices in 19 US cities. Using a series of panel unit-root tests, they find a surprisingly low speed of convergence, with a half-life of about 9 years. Moreover, they are unable to reject the null of non-stationarity in price differentials when examined in univariate a unit-root tests.

Finally, Imbs *et al* (2005) analyze the possible aggregation bias in estimating the speed of convergence to the LOOP. They argue that failing to account for heterogeneity across product categories for realistic price dynamics produces downward-biased estimates of the speed of convergence, leading to upward-biased estimates of the half-life of price differentials. They also demonstrate that the bias can be economically substantial: the estimated half-life is 39 months in a fixed effect panel model using price data in the European Union, while the same figure is 27 months in more dis-aggregated, sector level data. The results in general suggest that the appropriate testing ground for the study of price differentials are in microeconomic price data, as pursued in the current study.

[4] Estimating specifications with quadratic terms for distance and population show no statistically significant non-linear effects.

6 CONCLUSION

This study analyses the *intra*-country convergence of price differentials using a relatively long, monthly frequency panel of prices of highly dis-aggregated items in Hungary. The advantages of using microeconomic price data from the same country are manifold. First, it mitigates the role of exchange rate fluctuations, factor and good market separation and barriers to trade in accounting for the speed of convergence in price differentials across different geographic locations. In addition, the use of micro level price data allows for controlling aggregation effects potentially biasing inference on the extent of non-stationarity.

In contrast to a large portion of the literature on Purchasing Power Parity and the LOOP, the findings here strongly reject the null hypothesis of price differentials being non-stationary. Indeed, the implied half-lives in general show very fast convergence in prices. The speed is however slower for non-tradable services than for tradable food items. If interpreted as fast convergence to a potentially non-zero time-invariant price differential, the LOOP appears to rule. Finally, the time-invariant price differential depends negatively on market size, proxied by the population in the county, and positively on the distance of the main city from the benchmark location.

The degree of persistence in price differentials may have crucial implications for inflation dynamics in countries of joining the EU and eventually the EMU. The major potential tension is between the economic and monetary integration of currently low-price accession countries bringing about price level convergence and the need of keeping inflation at levels appropriate for monetary integration in these countries. The true quantitative consequences of this tension are determined in turn by the extent to which inflation differences are explained by forces other than convergence in price levels.

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FIGURE I

Annual CPI Inflation in Hungary

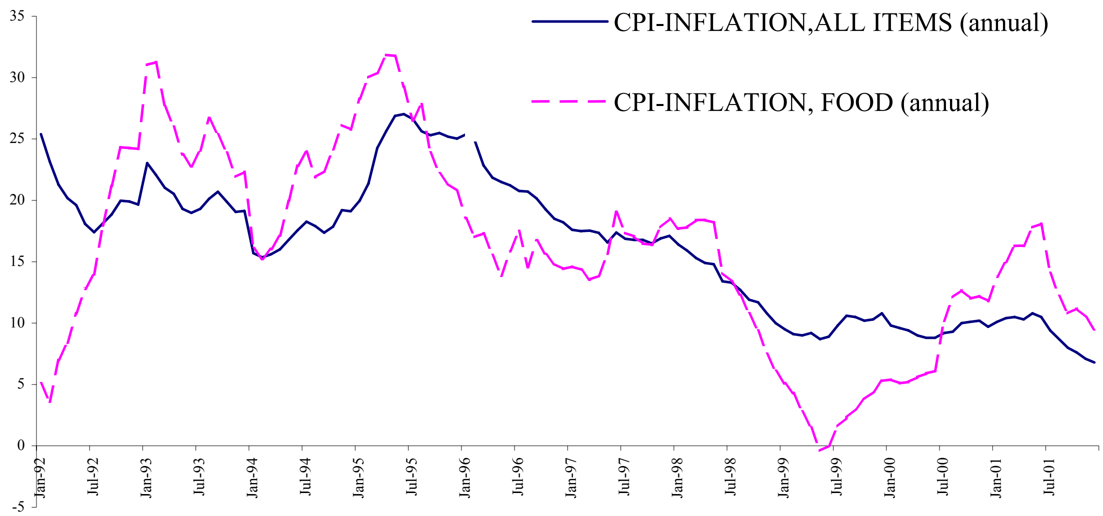

TABLE I
PRODUCTS IN THE SAMPLE

Product Code	Product Name	Type of Product	Absolute Weight	Relative Weight	Mean	Standard Deviation
10001	Pork, Chops	p	0.49	13.65	1.22	5.09
10002	Spare Ribs, with Bone	p	0.19	5.29	1.55	5.21
10003	Pork, Leg without Bone and Hoof	p	0.77	21.45	1.18	5.36
10102	Beef, Round	p	0.04	1.11	1.83	2.38
10103	Beef, Shoulder with Bone	p	0.04	1.11	1.97	2.46
10301	Pork Liver	p	0.12	3.34	1.75	2.86
10603	Sausage, Italian Type	p	0.17	4.74	1.71	2.88
10605	Sausage, Boiling	p	0.17	4.74	1.80	2.91
10801	Carp, Living	p	0.06	1.67	1.93	1.87
11302	Curd, 250g	p	0.16	4.46	2.33	3.67
12101	Lard, Pork	n	0.13	3.62	2.10	8.06
12201	Fat Bacon	n	0.07	1.95	2.81	3.85
12203	Smoked Boiled Bacon	n	0.07	1.95	2.62	3.90
13002	Flour, Prime Quality	n	0.28	7.80	1.98	3.35
13501	Sugar, White, Granulated	n	0.53	14.76	1.59	2.55
13801	Dry Biscuits, without Butter, Packed	n	0.05	1.39	1.63	1.86
14424	Tomato Paste	n	0.03	0.84	1.41	1.91
15208	Vinegar, 10 hydrate	n	0.05	1.39	1.19	2.99
66105	Car Driving School, Full Course	s	0.16	4.46	2.58	7.85
66301	Movie Ticket, Evening, 1-6 Rows	s	0.01	0.28	2.19	1.64
			3.59	100.00		

Notes 1 Figures are compiled from various consumer price statistic booklets of the Central Statistical Office, Hungary.
2 Products are narrowly defined according to size, branding, type and flavor.
3 Weights are expenditure-based. *Absolute Weight* is taken from the 1995 CPI. *Relative Weight* reflects weight of the item in this particular sample.
4 *Mean* is the average of monthly inflation rates. *Standard Deviation* is the standard deviation of monthly inflation rates.
5 The type of product can be perishable food (*p*), non-perishable food (*n*) and service (*s*). The classification is judgmental; it is based on a subjective examination of product characteristics.

TABLE II
LOCATIONS IN THE SAMPLE

Code	County / Main City	Population	Distance to Budapest
2	Baranya / Pécs	405 000	197
3	Bács-Kiskun / Kecskemét	545 000	83
4	Békés / Békéscsaba	396 000	203
5	Borsod-Abaúj-Zemplén / Miskolc	745 000	178
6	Csongrád / Szeged	427 000	169
7	Fejér / Székesfehérvár	428 000	65
8	Győr-Moson-Sopron / Győr	436 000	124
9	Hajdú-Bihar / Debrecen	552 000	226
10	Heves / Eger	325 000	127
11	Komárom-Esztergom / Tatabánya	317 000	57
12	Nógrád / Salgótarján	219 000	112
13	Pest / Cegléd	1 106 000	70
14	Somogy / Kaposvár	336 000	188
15	Szabolcs-Szatmár-Bereg / Nyíregyháza	586 000	245
16	Jász-Nagykun-Szolnok / Szolnok	416 000	98
17	Tolna / Szekszárd	249 000	142
18	Vas / Szombathely	267 000	221
19	Veszprém / Veszprém	374 000	109
20	Zala / Zalaegerszeg	298 000	227
1	Budapest / Budapest	1 725 000	0

Notes 1 The county codes and the population data are compiled from the appropriate booklets of the Central Statistical Office, Hungary.
2 The distance figures represent the distance between the main city in the county and Budapest, taken from the official roadmap of Hungary.

TABLE III
SPEED OF CONVERGENCE

Product Code	Product Name	Type of Product	Coefficient	*t* value	Half-Life
10001	Pork, Chops	p	-0.267	-12.04	2.23
10002	Spare Ribs, with Bone	p	-0.232	-12.94	2.63
10003	Pork, Leg without Bone and Hoof	p	-0.256	-13.27	2.34
10102	Beef, Round	p	-0.132	-10.51	4.90
10103	Beef, Shoulder with Bone	p	-0.096	-8.81	6.87
10301	Pork Liver	p	-0.088	-7.67	7.52
10603	Sausage, Italian Type	p	-0.177	-10.82	3.56
10605	Sausage, Boiling	p	-0.118	-7.81	5.52
10801	Carp, Living	p	-0.213	-12.86	2.89
11302	Curd, 250g	p	-0.111	-9.50	5.89
12101	Lard, Pork	p	-0.272	-13.99	2.18
12201	Fat Bacon	p	-0.130	-8.59	4.98
12203	Smoked Boiled Bacon	p	-0.151	-9.37	4.23
13002	Flour, Prime Quality	n	-0.169	-10.06	3.74
13501	Sugar, White, Granulated	n	-0.219	-12.19	2.80
13801	Dry Biscuits, without Butter, Packed	n	-0.197	-11.12	3.16
14424	Tomato Paste	n	-0.078	-6.97	8.54
15208	Vinegar, 10 hydrate	n	-0.173	-9.70	3.65
66105	Car Driving School, Full Course	s	-0.068	-8.53	9.84
66301	Movie Ticket, Evening, 1-6 Rows	s	-0.056	-8.05	12.03
	Mean		-0.16		4.98
	Median		-0.16		3.99
	Standard Deviation		0.07		2.75

Notes: See Table I.

TABLE IV
SPEED OF CONVERGENCE – ABSOLUTE LOOP

Product Code	Product Name	Type of Product	Coefficient	*t* value	Half-Life
10001	Pork, Chops	p	-0.061	-5.07	11.01
10002	Spare Ribs, with Bone	p	-0.152	-9.81	4.20
10003	Pork, Leg without Bone and Hoof	p	-0.080	-7.42	8.31
10102	Beef, Round	p	-0.024	-4.02	28.53
10103	Beef, Shoulder with Bone	p	-0.058	-6.57	11.60
10301	Pork Liver	p	-0.037	-4.82	18.38
10603	Sausage, Italian Type	p	-0.058	-5.86	11.60
10605	Sausage, Boiling	p	-0.057	-4.81	11.81
10801	Carp, Living	p	-0.045	-4.56	15.05
11302	Curd, 250g	p	-0.083	-7.99	8.00
12101	Lard, Pork	p	-0.173	-10.78	3.65
12201	Fat Bacon	p	-0.040	-5.84	16.98
12203	Smoked Boiled Bacon	p	-0.086	-6.79	7.71
13002	Flour, Prime Quality	n	-0.046	-5.35	14.72
13501	Sugar, White, Granulated	n	-0.145	-9.87	4.42
13801	Dry Biscuits, without Butter, Packed	n	-0.079	-6.25	8.42
14424	Tomato Paste	n	-0.036	-4.64	18.91
15208	Vinegar, 10 hydrate	n	-0.060	-5.87	11.20
66105	Car Driving School, Full Course	s	-0.022	-4.25	31.16
66301	Movie Ticket, Evening, 1-6 Rows	s	-0.006	-2.52	115.18
	Mean		-0.067		18.04
	Median		-0.058		11.60
	Standard Deviation		0.044		23.99

Notes: See Table I.

TABLE V
DISTANCE AND POPULATION REGRESSION

Variable	Coefficient Estimate	*t* statistic	*p* value
Constant	-0.030	-1.75	0.10
Population	-0.041	-2.12	0.05
Distance	0.023	13.27	0.73
R^2	0.23		
F test	2.45		

Notes 1 Distance is measured in 100 km.
2 Population is measured in million people.
3 The dependent variable is the average of demeaned price differentials.