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Price convergence in the EMU? Evidence from micro data

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Abstract:

The establishment of European monetary union (EMU) was widely expected to cause price convergence among member states. In an investigation of this claim, the present study avoids problems of comparability and representativeness by using an extremely detailed and comprehensive scanner database on washing machine prices and sales volumes for 17 European countries. A hedonic regression yields country-specific time series for quality-adjusted price differentials. Statistically and economically significant deviations from the LOP emerge. Log t tests firmly reject price convergence among EMU countries. Small convergence clusters can be identified but they are unrelated to EMU membership.

Keywords: price convergence, LOP, euro introduction, log t test, hedonic price regression, scanner data

JEL-Classification: F36, F31, E31, L68, C23

Non technical summary

The introduction of the euro was widely expected to cause product prices in the emerging monetary union to converge to a low level by raising transparency and cutting transaction costs. Available empirical studies on this issue have yielded contradictory results. They have been subject to some specific problems, however. First, the earlier papers, in particular, covered only a very short period after the establishment of European Monetary Union (EMU), thus rendering statements on the effect of euro introduction rather uncertain. Second, the reliability of the international price comparisons has been constrained by the limited comparability of the chosen goods and by the relatively small number of prices sampled. Finally, the statistical methods for the measurement of convergence may not have been entirely appropriate.

The present study addresses each of these shortcomings. It is based on an extremely detailed and comprehensive scanner database on actually paid washing machine prices and sales volumes for 17 European countries covering the period from 1995 to 2005. Thus, it includes a comparatively long period in which the price adjustment could have occurred. A hedonic regression yields time series of quality-adjusted relative prices for EMU and non-EMU countries. By this means, problems of limited international comparability of prices are avoided. Finally, a test of convergence recently developed by Phillips and Sul (2007) is used which overcomes some of the problems associated with more traditional measures of convergence.

The results of the study confirm earlier findings of statistically and economically significant deviations from the Law of One Price. It is also shown that quality-adjusted washing machine prices did not exhibit any tendency to converge across EMU members; if anything, a tendency for divergence appears to be prevalent. Moreover, a convergence cluster analysis cannot identify any convergence club which comprises a larger subgroup of EMU countries and, at the same time, excludes the non-EMU countries in the sample. Instead, the clusters that have been found are mostly rather small and are usually unrelated to EMU membership suggesting that forces other than the euro have promoted price convergence.

This implies that neither the introduction of the euro at the start of 1999 nor the euro cash changeover three years later have had a noticeable price convergence impact. More detailed conclusions should only be drawn with caution. It is unclear whether the results for washing machines can be generalised. It should also be kept in mind that the convergence process may take even more time meaning that the results may still need to be considered as being preliminary. Finally, it cannot be ruled out that, as long as a deeper understanding of the ultimate determinants of price convergence or divergence is lacking, the convergence impact of monetary union is swamped by other factors.

Nicht technische Zusammenfassung

Vielfach ist erwartet worden, dass die Euro-Einführung zu einer Konvergenz der Preise identischer Güter innerhalb des entstehenden gemeinsamen Währungsraums führen würde. Begründet wurde diese Auffassung mit steigender Preistransparenz und der Verringerung von Transaktionskosten. Bisherige empirische Untersuchungen dieser Hypothese kommen zu keinem einheitlichen Ergebnis. Diese Arbeiten waren allerdings auch mit einer Reihe von Problemen konfrontiert, die bisher nur zum Teil gelöst worden sind. Zum einen war insbesondere in den frühen Untersuchungen der Zeitraum seit Beginn der Europäischen Währungsunion (EWU) noch sehr kurz, so dass eine Aussage über den Einfluss der gemeinsamen Währung nur bedingt möglich war. Zweitens krankten die internationalen Preisvergleiche daran, dass sie sich in der Regel auf nur eingeschränkt vergleichbare Güterbündel oder auf eher stichprobenartige Erfassungen von Preisen stützen mussten. Schliesslich sind oftmals statistische Konzepte zur Messung der Konvergenz verwendet worden, die nur teilweise befriedigen.

Die vorliegende Untersuchung stellt hinsichtlich jedem dieser Aspekte eine deutliche Verbesserung dar. Sie verwendet einen ausgesprochen detaillierten und umfassenden Scanner-basierten Datensatz über tatsächlich gezahlte Waschmaschinenpreise und zugehörige Verkaufsmengen in 17 europäischen Ländern von 1995 bis 2005. Zum ersten ist damit ein vergleichsweise langer Zeitraum für die Identifikation der erwarteten Preisanpassung enthalten. Zum zweiten erlaubt eine hedonische Regression die Berechnung von Zeitreihen qualitätsbereinigter Relativpreise für Länder innerhalb und außerhalb der Währungsunion. Auf diese Weise vermeidet die Studie Probleme mangelnder internationaler Vergleichbarkeit der Preise. Zum dritten schließlich verwendet das Papier einen Test auf Konvergenz, der kürzlich von Phillips und Sul (2007) entwickelt worden ist und der einige Unzulänglichkeiten traditioneller Konvergenzmaße überwindet.

Die Untersuchung stellt zunächst statistisch und ökonomisch signifikante Abweichungen vom Gesetz der Unterschiedslosigkeit der Preise fest und bestätigt auf diese Weise frühere Resultate aus der Literatur. Sie zeigt zudem, dass sich qualitätsbereinigte Waschmaschinenpreise in der Währungsunion keineswegs länderübergreifend aneinander angenähert haben, eher ist das Gegenteil der Fall. Darüber hinaus kann auch nicht festgestellt werden, dass eine größere Teilmenge von Ländern der Währungsunion einen EWU-spezifischen „Konvergenzclub“ gebildet hätte. Die tatsächlich gefundenen „Konvergenzclubs“ sind vielmehr klein und nicht auf EWU-Mitglieder beschränkt, so dass man vermuten kann, dass andere Einflüsse als die gemeinsame Währung die Annäherung gefördert haben.

Diesen Ergebnissen zufolge hatte also weder die eigentliche Euro-Einführung zu Beginn des Jahres 1999 noch die Euro-Bargeldeinführung drei Jahre später einen wahrnehmbaren, die Preiskonvergenz identischer Güter stimulierenden Effekt. Weitergehende Schlussfolgerungen sollten aber nur mit Vorsicht gezogen werden. Unklar ist zunächst, inwieweit die Ergebnisse für Waschmaschinen verallgemeinert werden können. Zweitens ist das Ergebnis insofern vorläufig, als der Konvergenzprozess möglicherweise noch mehr Zeit benötigt. Solange die Triebkräfte von Konvergenz und Divergenz nicht besser erklärt werden können, ist schließlich nicht ausgeschlossen, dass unser Befund auf eine Überlagerung der Konvergenzkräfte der Währungsunion durch andere Faktoren zurückgeht.

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1 Introduction

One of the benefits which had been expected from the foundation of the European Monetary Union (EMU) was a reduction of product price differences between member countries. Within the EMU, the abandonment of national currencies should have raised transparency and eliminated all the costs associated with the exchange of currencies thus cutting transaction costs and narrowing the scope for deviations from the Law of One Price (LOP).

The difficulties of international price comparisons are well known. Most recent studies of price convergence in Europe use relative price level data for many categories of goods and services which are based on price collections of one or a few exemplary variants of the product category in a few outlets in a few cities. However, one may question the accuracy of such relative price levels in terms of representativeness for the product category and for the country in question as well as in terms of homogeneity and thus comparability of the items considered.[2] The uncertainty around such figures is reflected in substantial revisions of economy-wide aggregated relative price levels.[3] A

[1] The paper represents the author's personal opinions and does not necessarily reflect the views of the Deutsche Bundesbank. I would like to thank Jörg Breitung, Mario Crucini, Ulrich Grosch, Heinz Herrmann, Joachim Keller, Axel Weber and Alexander Wolman for valuable suggestions and comments. I am especially grateful to Torsten Meyer of GfK Retail and Technology who once and again gave invaluable advice concerning the data, Sebastian Kohler who helped in data processing, and Eurostat staff, especially Konstantinos Panagopoulos, for the provision of Eurostat data and the permission to use them for publication. All remaining errors are my own.

[2] A comparison between official data published by Eurostat and the washing machine micro data used here is presented in appendix 2. The results may be interpreted as indicating a limited representativeness of official data.

[3] As an extreme example, China's PPP-based GDP has recently been revised downwards by about 40 percent because its aggregate relative price level had been revised upwards correspondingly; cf IMF (2008). Among European countries, Germany's aggregate relative price level for 2005 as recorded in the European Commission's "Annual macro-economic database" has been revised downwards by 4%, Luxembourg's by 8% and Norway's by 11% in 2007. Since the aggregate is computed from disaggregated relative prices for given products, some of which are revised upwards while others may have been revised downwards, the average absolute revision for a single product may be much larger than the figures given here.

biasedly measured price level, however, may make the difference between convergence or divergence.

The present study avoids these problems by using an extremely rich database for the European washing machine market. It contains prices, quantities sold as well as a large number of characteristic features of each washing machine model purchased in each of 17 larger EMU and non-EMU countries. The comprehensive coverage of the markets guarantees representativeness, the wealth of model characteristics makes it possible to establish homogeneity and comparability. Since the data is based in large part on scanner recording of transactions, actually paid prices inclusive of all discounts instead of list prices are recorded. All this contributes to an especially high reliability of the international price comparisons in this study.[4]

Admittedly, the selection of a specific product market precludes outright conclusions concerning entire economies. Washing machines, however, are especially suitable for an analysis of international price convergence since they are highly tradable and highly traded, they are non-perishable and each model belongs to a brand which facilitates international comparisons. If anywhere, a reduction in transaction costs caused by the introduction of the euro should be detectable in such a market (see also Allington et al, 2005).

In contrast to many earlier studies, the washing machine database covers a significant post-EMU period. This may be beneficial if the expected effects of the introduction of the euro take some time to materialise, as it is discussed in Engel/Rogers (2004). The finding of Parsley/Wei (2001) that price differentials are particularly small in those currency unions which have existed for a long time, as for instance in the Belgium-Luxembourg one, supports such a hypothesis.

Apart from the exceptionally high reliability of price comparisons and the long post-EMU data span, the present study's contribution to the literature includes the application of a newly developed convergence test, Phillips/Sul's (2007) "log *t*" test,

[4] Goldberg/Verboven (2004, 2005) investigate price convergence issues on the European car market using a database of similarly extensive coverage and richness. The high degree of segmentation along borders through selective and exclusive distribution channels as well as national systems of type approval and registration, however, make the European car market rather peculiar and possibly much less susceptible to the effects of the introduction of the euro. Moreover, they use list prices and the post-EMU period covered in their studies is short.

which overcomes some problems of more traditional measures of convergence and enables the identification of convergence clusters.

Turning to the results, we first confirm earlier findings of still statistically and economically significant deviations from the LOP in EMU by estimating a hedonic regression. Second, we are unable to provide any evidence in favour of price convergence across euro area countries. If anything, price dispersion has risen since the turn of the millennium. The log *t* convergence test suggests the existence of some smaller convergence clubs in Europe but their membership pattern is unrelated to participation in EMU.

Section 2 gives a short literature overview. In section 3, a conceptual framework is presented which guides the empirical analysis afterwards. Section 4 gives an overview of the data and includes the results of the hedonic regression. Section 5 presents some insights into the validity of the LOP in Europe and section 6 introduces the convergence test methods and results. Section 7 concludes.

2 Previous studies on deviations from the Law of One Price and price convergence in the EMU

First empirical investigations on price convergence effects of EMU were performed soon after its inception.[5] The evidence so far is mixed, however. Early studies such as those of Lutz (2004) and Engel/Rogers (2004) were unable to find any evidence of price convergence that could be ascribed to the foundation of EMU. Some of the more recent studies, for instance Cuaresma et al (2007), who focus explicitly on the euro cash changeover, and Rogers (2007), yield similar results. Goldberg/Verboven (2004) who concentrate on the European car market come to slightly different

[5] For such an analysis, a point in time needs to be determined where the introduction of the euro could possibly have started to trigger price convergence. Generally, the process of the establishment of EMU brought about two alternative times which may have been relevant in this respect. The first is the actual introduction of the euro on 1 January 1999. As of this date, the exchange rate between national currencies within the EMU were irrevocably fixed and the newly established Eurosystem was responsible for performing a common monetary policy. Coins and notes, however, continued to exist exclusively as national currencies, although they were manifestations of the common currency, the euro, just expressed in different units of account. At the start of 2002, euro coins and notes finally replaced national currencies. It has been claimed that both these events have reduced transaction costs and thus have contributed to price level convergence, the establishment of EMU by eliminating costs of exchange, the cash changeover by increasing price transparency.

conclusions: car price differentials fell significantly after 1999. Since 2002, however, price differentials in a non-EMU control group decreased even faster. Fischer (2007) reports slight indications of price level convergence which arise, however, only after 2002. The study of Allington et al (2005) is clearly the most positive one: They report significant evidence in favour of a reduction of price dispersion caused by the establishment of EMU.

The difficulties in proving unambiguously that EMU caused a reduction in price dispersion or that there is evidence of price convergence in the EMU at all stand in stark contrast to the highly uncontroversial finding that, before EMU, European prices converged considerably: Engel/Rogers (2004), Faber/Stokman (2005), Fischer (2007), Goldberg/Verboven (2005), Hill (2004), Rogers (2007) and Wolszczak-Derlacz (2006) are relevant examples, most of which suggest an especially pronounced advance in price convergence in the early nineties.

These results naturally give rise to the question whether there has been scope enough for EMU to reduce price dispersion further. Engel/Rogers (2004), for instance, put forward that their negative result concerning an EMU-related price convergence effect may be due to the highly effective market integration efforts in the European Union in pre-EMU times which resulted in low price dispersion in the late nineties. By contrast, studies such as Asplund/Friberg (2001), Haskel/Wolf (2001) or Mathä (2006) use micro data to show that even in the late nineties, considerable deviations from the LOP continued to exist in Europe. Rogers (2007), however, points out that, since the late nineties, price dispersion in the common currency countries has been close to that of the USA. He also notes, however, that distances between agglomerations are much larger in the USA, which would usually indicate a higher degree of price dispersion. Interestingly, Crucini et al (2001) and Mathä (2006) find that deviations from the LOP are much smaller between Belgium and Luxembourg, two small countries who formed a de facto monetary union in 1922, than between Belgium and other EMU members.

3 Conceptual framework

The expectation of price convergence caused by the establishment of monetary union is expressed vividly in a comment from the European Central Bank (ECB) on the euro cash changeover of January 2002: "... the introduction of the euro banknotes and coins further reduces transaction costs and increases price transparency across borders. In turn, this should increase the strength of competition and, over time, reduce price level dispersion in the euro area" (ECB, 2002, p 39). Similar statements have been made by the European Commission (1990, p 19, 1996, p 74, or 2008, pp 34-35) concerning the introduction of the euro in January 1999.

A conceptual framework related to that of Engel/Rogers (1996, 2004) or Crucini et al (2005) illustrates what the EMU founders may have had in mind. Consider a final good that is produced as a combination of traded and non-traded inputs and is sold in countries i and j. For internationally traded goods, for example for washing machines, the non-traded component in the destination country will consist mainly in distribution inputs. Using a Cobb-Douglas technology, the price of the good in country i is determined by

$$P_i = A_i W_i^{\gamma} Q_i^{1-\gamma} \tag{1}$$

where Q_i is the price of the traded and W_i that of the non-traded input (in the case considered here the washing machine as it arrives at the distributor and the distribution costs, respectively), and γ is the share of the non-traded input which is assumed to be the same across countries but not across goods. With perfect competition in the distribution sector, A_i is inversely related to total factor productivity of this sector; if distributors are monopolists instead, A_i additionally includes a mark-up. For the traded input, arbitrage ensures that the deviations from the law of one price (LOP) between countries i and j are bounded by trade costs,[6]

$$\frac{1}{\tau_{ij}} \leq \frac{Q_i}{Q_j} \leq \tau_{ij} \tag{2}$$

where Q_j denotes the traded input price in country j expressed in the currency of country i, and $\tau_{ij} - 1$ the *ad valorem* tax equivalent of broadly defined trade costs on

[6] See eg Engel/Rogers (1996). Anderson/van Wincoop (2004) show that arbitrage limits Q_i/Q_j to an even narrower interval than that given in equation (2). This, however, requires further knowledge about the production locations and the direction of trade of the good considered.

shipments between countries i and j. If trade costs are equivalent to a 30 % tax on prices, for instance, Q_i will fall in the interval $[0.77Q_j; 1.3Q_j]$.

It was expected that both the introduction of the euro and the euro cash changeover would lower trade costs τ_{ij} by reducing information costs through enhanced price transparency and by lowering costs associated with the exchange of currencies including the abolition of exchange rate risk, such that $1 \leq \tau_{ij,post} < \tau_{ij,pre}$ where *pre* (*post*) refers to the time before (after) the monetary integration step considered has been realised. To the extent that the relative input price Q_i/Q_j fell in one of the intervals $]\tau_{ij,post}; \tau_{ij,pre}]$ or $[1/\tau_{ij,pre}; 1/\tau_{ij,post}[$, it would adjust to the new narrower price interval. This would *ceteris paribus* entail a corresponding adjustment of the relative final good's price P_i/P_j and finally, in the aggregate, result in a decreased price level dispersion in the EMU.

4 Data and the hedonic price regression

4.1 The adequacy of focusing on the washing machine market

For the purpose of identifying a reduction in price dispersion due to the introduction of the euro, the focus on the washing machine market may be especially suitable. First, washing-machines are highly tradable and highly traded, which implies that $1-\gamma$ should be relatively large. Therefore, the expected changes in Q_i/Q_j due to EMU should be rather less vulnerable to being masked by developments in the distribution sector in their effects on P_i/P_j. It cannot be ruled out, of course, that some developments specific to the washing machine market concerning for instance the distributors prevent the effect from being detectable; however, we do not see any reason why the washing machine market should differ in such a way from other highly traded goods.

Second, washing machines belong to brands which, in most cases, are well-known internationally, and each model is identified by a specific model name and a corresponding set of physical characteristics. This ensures a very high degree of homogeneity across countries[7] and facilitates international comparability and – if

[7] In fact, if a specific model is listed for several countries with an identical combination of physical characteristics, it is the identical model. There will be cases, however, in which an identical model is given a different model name in different countries.

necessary – quality adjustment of the prices. Both reasons imply that restricting the analysis to the washing machine market should raise the probability of detecting price convergence as a consequence of the introduction of the euro. If the analysis does not yield any evidence for the expected effect in the washing machine market, one could be sceptical as to whether an aggregate effect can have occurred at all. The possibility of potential market-specific developments should, however, be kept in mind.

4.2 The data

The data used for the analysis covers nearly the entire washing machine market in each of 17 European countries. The raw data was obtained from GfK Retail and Technology, a market research bureau, which collects data from retailers, aggregates it and sells it inter alia to producers, distributors, component suppliers and public institutions. Technically, universe studies are performed on a regular basis while, in a much higher frequency, data is collected for a sample which is stratified by distribution channel. For each model, sales prices and volumes are surveyed in a given period. Based on the results of the universe studies, these figures are projected separately for each distribution channel onto the universe. The extrapolated data covers on average 90 % of all washing machine sales in the countries considered. Aggregation across distribution channels yields the economy-wide number of sales and an average price for each model on the market. Since around 90 % of the data is collected in the first place as electronic ("scanner") data, ie by enterprise resource planning systems, and the rest by regular, manual store audits, it is ensured that prices are not list prices but instead actually paid prices that take any discounts into account.

The data used for the analysis spans the three dimensions of washing machine model, country and time. The observation period runs from 1995 to 2005. At its start, data for 11 of the larger European countries are available: Austria, the Czech Republic, France, Germany, Hungary, Italy, the Netherlands, Poland, the Slovak Republic, Spain, and the United Kingdom. Later on, Belgium, Sweden, Portugal, Greece, Denmark, and Finland were added. In the earlier part of the observation period, data is provided in a frequency of three times per annum for some countries and every other month for others. Later on, all the data is provided in a two-monthly frequency. Apart from prices and quantities, each model is characterised by a number of physical features such as spinning speed, load capacity etc. The structure of the data suggests combining it into two alternative samples: Sample 1 covers the complete observation period as far as it is available for each of the 17 countries. Each model is characterised by five physical features. Price and quantity data is considered in a *frequency of three times a year*. Sample 2 starts in 2000, contains 21 characteristics per model, and prices and quantities in a *two-monthly frequency*.[8] It is useful to consider both samples because the first spans a longer observation period while the second, being more detailed in terms of frequency and model characteristics, may provide an even more accurate picture.

Tables A1 and A2 in appendix 1 illustrate the richness of the data: the number of models sold in a four-month period[9] ranges from 50 in the Slovak Republic to 1787 in Italy. Model variety has increased especially steeply in the non-EMU central European countries. In a cross-country comparison it is not surprising that model variety tends to rise with the size of the market. As a deviation from this rule, however, the model variety is continually highest in Italy although this country is not the largest washing machine market in Europe. The high model variety may be related to the abundance of independent small-scale distributors in Italy. This is also reflected in the average quantity of units sold per model in a four-month period. This figure generally increases with country size as well but, for Italy (301), it ranges even lower than for Poland (444) or Spain (346). Interestingly, the UK (1355) is the country for which by far the highest average quantity of a given model is sold. This may be an implication of the abundance of mail order business in the UK and the high concentration in the distribution sector. Not surprisingly, large standard deviations (not shown in the table) illustrate the considerable differences in market success of different models.

The reported washing machine prices, $P_{V,it}$, are inclusive of VAT where i denotes country and t is time. However, international trade of firms is generally subject to the destination principle. Therefore, prices net of VAT, P_{it}, should be more relevant for international price comparisons within the EU. Washing machine prices have thus been

[8] Apart from the increase in coverage over time in terms of countries, frequency, and the number of physical features for the characterisation of a model, the separate analysis of a shorter sample is suggested by the fact that data pertaining to the period before the turn of the millennium has been provided in a separate database that had first to be matched with the database containing the more recent data.

[9] The figures in this paragraph refer to table A1 which describes sample 1. As can be seen from table A2, however, sample 2 gives rise to the same observations.

corrected for VAT. Percentage VAT rates, V_{it}, for each of the countries in the sample over the whole observation period have been obtained from the European Commission (2006) and have been deducted as $P_{it} = P_{V,it}/(1+V_{it}/100)$. All results presented refer to net prices; some calculations, however, have additionally been performed using prices inclusive of VAT, in particular the hedonic price regression and the log t price convergence tests. Differences in the results have been small.

Figure 1 shows average net washing machine prices from sample 1 over time. Figure 1a covers EMU countries, figure 1b non-EMU countries. Prices are expressed in D-Mark because the euro did not yet exist in the first years of the observation period. In the calculation of the average, the price of a model is weighted by the quantity sold. Inside the EMU, net prices are highest in Germany, Austria, the Netherlands and Belgium and lowest in Portugal, Italy and Spain. At the turn of the millennium, an apparent conspicuous fall in German and Austrian prices stands out. This is due to the fact that washing machines sold in mail order business in these countries are fully covered only from the start of 2000 onwards. Among non-EMU countries, Denmark reports the highest prices and Hungary the lowest.

Since a slight trend towards a decrease in prices appears to be more pronounced in high-price countries than in low-price countries, visual inspection may suggest a small decrease in price dispersion. However, price differences across countries as well as price movements may simply be governed by quality. The low prices in recent EU accession countries, for instance, could be due to their relatively low income in the sense that it may result in a preference for washing machines of a comparatively low quality. By the same token, the visual impression of price convergence may result from the more than proportional increase in income in these countries leading to an especially fast upgrade in the quality of washing machines sold there.

4.3 A hedonic price regression

In order to adjust prices for quality, a hedonic price regression has been estimated.[10] Similar to Goldberg/Verboven (2005), a semi-logarithmic functional form has been chosen:[11]

$$\ln P_{ikt} = \pi_0 + \pi'_{\omega}\omega_k + \pi_f + \pi_{it} + \varepsilon_{ikt} \tag{3}$$

where P_{ikt} denotes the price of washing machine model k in country i at time t net of VAT, $\omega'_k = (\omega_{k1}\ \omega_{k2}\ ...\ \omega_{km(\omega)})$ is a vector of $m(\omega)$ physical characteristics of model k and $\pi'_{\omega} = (\pi_{\omega 1}\ \pi_{\omega 2}\ ...\ \pi_{\omega m(\omega)})$ a vector of corresponding coefficients, π_f is the coefficient on a firm dummy which takes on a value of 1 for all models that are produced by the producer of model k and is 0 elsewhere, π_{it} is the coefficient on a country-time dummy and ε_{ikt} is an iid error term.

The vector of characteristics is designed to capture observable differences between different models. Note that the combination of characteristics for a given model does not depend on country or time. Characteristics comprise 13 numeric and non-numeric features in sample 2 and 5 features in sample 1. They include, for instance, the spinning speed or the presence of a drying function.

Firm or brand dummies are included in equation (3) in order to account for unobservable differences in quality between alternative models. Some brands are well known for the reliable workmanship, the long life-time or the high robustness of their products and are thus able to charge a higher price for an otherwise identical product. Other brands may be successful in creating a distinct brand image through advertisement, which may allow them to charge higher prices. There are 471 brands in

[10] Since many models are sold in only a few or even in only one of the countries covered, a comparison of individual models would cover only a fraction of the market. In many cases, it may just have been the name of the model which differs between countries. With the available data, however, it is hard to filter these effects out. As an alternative, one could have restricted the analysis to the most widespread and top-selling models. But this may exclude exactly those models whose relative prices may tend to be too large to be maintained within the monetary union. Moreover, the machines usually have a relatively short life-cycle, such that practically no model is sold over the entire observation period. This may, however, be a minor problem.

[11] In his study on hedonic regression of electrical appliances including washing machines, Hoffmann (1998) found that the functional form of the hedonic regressions had only a minor effect on the results. Equation (3) implicitly assumes that coefficients π_{ω} and π_f do not vary over time or across countries. It turns out that these coefficients do indeed change somewhat if the sample is restricted to the new millennium. The results concerning price convergence and deviations from the LOP, however, remain unaffected.

sample 1 and 407 in sample 2. Brand identity information is redundant for 21 brands in sample 1, which leaves $m(f) = 450$ brand dummies for the hedonic regression. In sample 2, $m(f) = 292$.

The residual of a regression on the observable and unobservable product characteristics is the quality-adjusted price premium of model *k*. Coefficients π_{it} measure how large this premium is on average in country *i* at time *t* relative to a base case. As the base case, the country-period combination with the most models has been chosen which is the second four-month period of 2001 in Italy for sample 1 and the fifth two-month period of 2005 in Italy for sample 2. Coefficients π_{it} of sample 1 are, therefore, the average quality-adjusted price deviation of the washing machines in country *i* at time *t* compared in percentage terms to the typical washing machine in Italy in 2001:2. Significant differences between the coefficients of two countries at a given time period, π_{it} and π_{jt}, can arise through trade costs (a deviation of Q_{it}/Q_{jt} from 1 in (2)) which should have been reduced by the introduction of the euro, or through differences in distribution-sector-related elements in (1), notably in distribution costs, W_{it}/W_{jt}, or in mark-ups, A_{it}/A_{jt}. For N = 17 countries and up to T = 33 observation periods in sample 1 (T = 36 in sample 2), 485 country-time dummies have been included in the hedonic regression for sample 1 and 587 for sample 2.

The hedonic price regression (3) has been estimated using a weighted least squares technique where the quantity of model *k* sold in country *i* at time *t* has been used as the weighting. Results are shown in table 1a for sample 1 and in table 1b for sample 2. Both regressions explains more than 87 % of the variation in net log washing machine prices. Apart from dummies for the residual category "unknown", all the hedonic coefficients are significant. Significance levels reach three-digit values in several cases. All the coefficients are signed as expected. Economic significance is substantial. To give some examples from sample 2, an additional kilogramme loading capacity raises the net price by 9 %, a rise in the spinning speed by 200 revolutions per minute adds 11 % to the price, a toploader or a built-in machine command a premium of 21 % and 35 %, respectively, the presence of a drying function adds 31 % to the bill, and costs are less than half, if the customer refrains from choosing a fully automatic machine (although it may be difficult to find a semi- or non-automatic one in the countries considered).

Most of the brand dummies are highly significant as well. This is reflected in the *p*-value of an F-test on their combined significance being indistinguishable from zero. The same applies to the country-time dummies. F-tests have been performed on the combined significance of all the dummies for a given country as well as for a given time period. The *p*-values of all these tests are again virtually zero, regardless of which country or which time period is chosen.

5 Deviations from the Law of One Price

The estimated coefficients of the country-time dummies, $\hat{\pi}_{it}$, for sample 1 are depicted in Figure 2 as time series. These are the deviations of average quality-adjusted net washing machine prices in country *i* at time *t* from average prices in Italy in 2001:2. Figure 3 shows the corresponding time series based on sample 2. The observation period in figure 3 is shorter than that of figure 2 but the results should be more precise because of the distinctly extended set of quality characteristics available in sample 2.

A comparison between these figures and figure 1 reveals that the adjustment for quality substantially changes the ranking of countries according to their average washing machine prices. As opposed to figure 1, these figures show that, amongst all EMU countries, prices are highest in France in 1997-2002, and subsequently in Greece or Italy, with Spain close behind. Prices are lowest in the Netherlands until 2001 and in Germany, Austria and Finland later on. Outside the EMU, it is mostly still Denmark and Sweden, in which washing machines cost most, and Hungary where they are cheapest.

Figure 2a reveals that the hedonic regression eliminates the abrupt fall in German and Austrian net prices in 2000:1 which was apparent in figure 1a. The most pronounced price changes over time after quality adjustment are the price increases in the UK and Italy around 1996. They are related to the nominal appreciation of both the pound sterling and the Italian lira against the D-Mark at that time which was quite similar in magnitude to the calculated quality adjusted price increase. This is a first sign of considerable violations of the LOP.

One of the measures used for gauging deviations from the LOP (see for instance Asplund/Friberg, 2001) are average absolute price deviations across countries. For a given point in time, this amounts simply to $\left|\hat{\pi}_{it} - \hat{\pi}_{jt}\right|$ for the bilateral country pair *i* and *j*. Averaging over time yields a more general measure for deviations from the LOP. They range from around 1½% between Belgium and Portugal to 40% between Greece and Hungary. All these bilateral absolute price deviations, even the lowest ones, are statistically significant at any sensible significance level. Economically, average price deviations of 1½% are rather unimportant. It should be borne in mind, however, that these values are averages for the entire washing machine market and may thus mask larger differences for individual models (downward aggregation bias of dispersion). Turning to the upper edge, average price deviations of 40% within the Single European Market for a good as tradable as a washing machine can hardly be brought in line with common perceptions of the LOP.

While the maximum deviation from the LOP within the EMU, though still substantial, is much smaller than these extremes (17% for the ratio between Germany and Greece), figures 2 and 3 give first hints as to whether this may be related to the introduction of the euro. In the full sample, in general, the maximum difference between quality adjusted prices hardly increases over time. According to sample 1, it is 40% in late 1998 when the euro introduction was imminent, still 40% at the end of 2001, just before the euro cash changeover took place, and 43% at the end of 2005 (for the country-pairs France/Hungary, France/Hungary and Greece/Hungary, respectively). The picture changes dramatically if one considers EMU members only. While the maximum quality-adjusted price difference stays nearly constant between the introduction of the euro and the euro cash changeover (16% between France and the Netherlands in 1998:3 and 16% between France and Austria in 2001:3), it rises steeply afterwards to reach 27% in 2005:3 (Germany/Greece). This suggests that price dispersion may have increased after the cash changeover instead of having fallen.

At the end of the observation period, the group of countries charging the highest prices consists of Greece, Italy, Spain and France, all of which are EMU members (Greece for five years and the other countries for seven) and all had been using euro coins and notes for four years already. Given the lower price levels in some EMU and all the non-EMU countries observed, the hypothesis that euro introduction would enhance competition and ultimately drive down prices to a common level sounds not (yet) convincing.

6 Evidence of price convergence?

In this chapter, formal tests of price convergence in the EMU are applied. Commonly used methods to test for price convergence are standard F tests on the equality of variances and panel unit root tests. These tests, however, are not specifically designed as convergence tests. On the one hand, panel unit root tests may classify the difference between gradually converging series as non-stationary. As a further problem, a mixture of stationary and non-stationary series in the panel may bias the results. Moreover, test results are sometimes not particularly robust. Standard F test results, on the other hand, may be arbitrary because they consider just two points in time instead of the whole series. As a further drawback, they assume independence of the two variances, which is often not the case in time series. The problem is especially pronounced if the price series are non-stationary.

Therefore, the log t test proposed by Phillips/Sul (2007) is used to test for price convergence. The test does not depend on particular assumptions concerning trend stationarity or stochastic nonstationarity of the variables to be tested. It focuses on the ultimate convergence of a country-specific component of the variables allowing for transitional divergence and heterogeneity in convergence speeds across panel members. It can further be used to identify convergence clusters. Since experience with applications of this method is scarce, the test results are contrasted with those of the more traditional methods mentioned above.

6.1 The log t test

Phillips/Sul's (2007) testing procedure is, in essence, a test of σ-convergence for a panel of time series. Their log t test consists in estimating

$$\ln\left(\frac{H_1}{H_t}\right) - 2\ln\left[\ln(t+1)\right] = a + b\ln t + u_t \qquad (4)$$

for $t = \text{int}(0.3T), \text{int}(0.3T) + 1, \ldots, T$, where

$$H_t = \frac{1}{N}\sum_{i=1}^{N}(h_{it} - 1)^2 , \qquad (5)$$

$$h_{it} = \frac{X_{it}}{N^{-1}\sum_{i=1}^{N} X_{it}} \tag{6}$$

and X_{it} is a smoothed version of the variable to be tested for convergence. A one-sided t-test using a heteroskedasticity and autocorrelation consistent (HAC) standard error of $\hat{b}$ tests for the null hypothesis of convergence, $b \geq 0$. As is shown in (5) and (6), the variable H_t is the cross-section variance of h_{it}, a normalised version of X_{it}. Since (the log of) the variance ratio H_1/H_t is regressed in (4) on a positive function of time, the log *t* test can be understood as a test on sigma convergence. Only data starting at $t = \text{int}(0.3T)$ is used for the regression in order to focus on long-term convergence. Phillips/Sul (2007) assume X_{it} to be the product of some common factor and a time-varying idiosyncratic coefficient which also includes a random component. Ultimately, the log *t* test tests for the convergence of this idiosyncratic component to some constant.

As in Goldberg/Verboven (2005) (who apply unit root tests, however), the country-time dummy series $\hat{\pi}_{it}$ are used for the formal analysis of convergence. Following the suggestion of Phillips/Sul (2007), an HP filter has been used to smooth these series. Since most of the series are already rather smooth (see figures 2 and 3), the smoothing factor λ has been adjusted from quarterly to the four- and two-monthly frequency of the series consistent with Hodrick/Prescott (1997) in a rather conservative way according to $\lambda = 1600 s^2$ where $s = \frac{3}{4}$ in sample 1 and $s = \frac{3}{2}$ in sample 2 resulting in $\lambda = 900$ and $\lambda = 3600$, respectively. Adding the estimated constant $\hat{\pi}_0$ to the series yields (log) smoothed price series for a washing machine of the default firm with the basic category characteristics. These are used as X_{it} in equation (6).

In the baseline case, the period considered starts in 1999:1, just when the euro had been introduced. This excludes Denmark and Finland which enter the samples later. Using the Newey-West procedure with a lag of 2 periods, the estimated t-value of $\hat{b}$ in (4) is -99.57 for all the countries in sample 1 and -168.65 if the sample is restricted to EMU countries (including Greece). Given a critical value of -1.65 at the 5% significance level, this suggests that washing machine prices in neither group have shown any tendency to converge. One may, of course, choose an earlier starting point to account for the possibility raised by Engel/Rogers (2004) that firms harmonised prices in anticipation. Starting two years earlier in 1997:1, however, yields values of -45.61 (entire sample 1) and -41.86 (EMU countries). If the starting point is 2000:1 and sample 2 is used, which may account for the effects of the euro cash changeover more accurately, values of -71.21 (entire sample) and -72.25 (EMU countries) are obtained. In sum, the null of price convergence is always firmly rejected.

The negative results may, however, be due to an outlier. A clustering algorithm recommended in Phillips/Sul (2007) is used to investigate whether some EMU countries may form price convergence clusters. If euro introduction caused price convergence, the algorithm should identify a convergence club which comprises most of the EMU countries and hardly any non-EMU countries. Results are provided in tables 2a-c. The first step of the algorithm consists of ordering the price series of individual countries according to the last observation, X_{iT}. This order is reflected in the baseline case shown in table 2a in the sense that the most expensive washing machines are sold in Greece, the second most expensive ones in Italy, the third in Spain and the cheapest ones in Hungary in the four last months of 2005. The first entry in column t refers to the result of a log t test which cannot reject the hypothesis that the subgroup Greece and Italy forms a convergence cluster. In the same manner, the existence of four further clusters is confirmed. Each of the clusters 3 to 5 comprises EMU and non-EMU countries.

If one lets the observation period start in 1997, Greece and Portugal are removed from the sample because of a lack of data. Table 2b shows that Italy and Hungary now no longer belong to any convergence club. The Slovak Republic, the UK and Germany are rearranged into the former cluster 4.[12] Starting in 2000 and using sample 2 yields the results shown in table 2c. Here, only two multi-country convergence clusters are left, both of which contain EMU as well as non-EMU countries. The t tests show that Greece, Italy, Spain, the Netherlands and Hungary do not belong to any convergence club. A description of the rather complex identification procedure for these clusters is exemplarily given in appendix 1.

[12] The resulting convergence clusters may not appear to exhibit any consistent geographic pattern. Such a pattern can, however, be blurred by the selection of countries for the convergence analysis. If the algorithm is applied, for instance, to the sample of EMU countries (start in 1997), a clear geographic pattern emerges: Italy being the most expensive country is followed by three clusters, the first of which comprises Spain and France, the second Belgium and the Netherlands and the third Austria and Germany.

The cluster convergence results do not provide evidence that the creation of EMU or the euro cash changeover might have resulted in any sort of convergence in washing machines prices. First, EMU countries are divided into many clusters and some of them may not even be related to any cluster at all. Second, the clusters that can be found are obviously unrelated to EMU membership.

6.2 Alternative approaches

Although the log t test may be the most appropriate for an investigation of price convergence, the results of two alternative, more widely used approaches will also be shown in order to check for robustness and in order to enable a closer comparison with previous studies. Several studies such as Parsley/Wei (1996), Ceglowski (2003) and Goldberg/Verboven (2005) use panel unit root tests for an examination of price level convergence for individual goods. A rejection of the null hypothesis of non-stationarity is commonly interpreted as evidence in favour of convergence to the LOP.

For an application of panel unit root tests, prices need to be normalised to a base country. Since it is well known that the choice of the base country often affects the test results (cf eg Coakley/Fuertes, 2000, or Papell/Theodorides, 2001), two alternatives have been used: Italy (IT) with the biggest variety of washing machine models and the country where most washing machines are sold within the EMU which is France (FR) in the case of sample 1 and Germany (DE) in the case of sample 2. The percentage deviation of the quality-adjusted washing machine price in country *i* from that in the base country IT, for example, is simply

$$r_{IT,it} = \pi_{it} - \pi_{IT,t} \,. \tag{7}$$

Since all the series in a given panel share a common base country, non-negligible cross-sectional correlations are to be expected. Therefore, it is advisable to apply second generation panel unit root tests, which take heterogeneous cross-correlations into account. In the present case, the multivariate homogeneous Dickey-Fuller (MHDF) test of Harvey/Bates (2002) and the panel corrected standard errors (PCSE) test of Breitung/Das (2005) and Jönsson (2005) have been used.

Tables 3a-c show that these tests cannot provide evidence in favour of stationarity for any panel of EMU countries, not even at a 10% significance level. This applies regardless of the lag length in the test equation and regardless of which observation period or sample is used. For a panel of all (EMU and non-EMU) countries, the results are also sobering. The results are fully consistent with those obtained using the log t tests. They contrast, however, with results from previous studies, notably those mentioned at the start of the chapter, which mostly find evidence for convergence to the LOP. One possible reason why the present study yields the opposite result may be its relatively short observation period. In any case, the finding of non-stationarity of price deviations across EMU countries does not lend support to the hypothesis that the introduction of the euro or the euro cash changeover has led to convergence of washing machine prices among member states.

A second alternative approach which is used in studies on price convergence such as Lutz (2004), Wolszczak-Derlacz (2006) and Rogers (2007) is a standard F test given by $\hat{\sigma}_s^2 / \hat{\sigma}_t^2 \sim F(N_s\text{-}1, N_t\text{-}1)$, where $\hat{\sigma}_s^2$ denotes the variance of price levels across N_s countries at time s. A rejection of the null hypothesis of the equality of variances implies $\hat{\sigma}_s^2 > \hat{\sigma}_t^2$, which is evidence for price convergence (divergence) if $t > s$ ($s > t$). For the present analysis, cross-country variances have been computed for five points in time, two alternative periods that precede the formation of EMU (1997:1 and 1998:3 in sample 1, which are respectively two years and immediately prior to the event), two corresponding ones that precede the euro cash changeover (2000:1 and 2001:6 using sample 2) and one at the end of the sample period seven and four years after the respective event. If some of the effects of the euro introduction occurred in anticipation before the event took place, the earlier pre-event point in time should be preferable, otherwise the latter should be more adequate.

As is shown in tables 4a and 4b, the equality of variances can generally not be rejected if convergence is the alternative hypothesis or if the full sample of countries is considered. If the alternative is divergence and the sample is restricted to the EMU countries, however, the equality of variances is rejected at the 5% significance level in three out of four cases and at the 10% level in the last. These results are again in line with the finding that neither the introduction of the euro nor the euro cash changeover is associated with a convergence of washing machine prices. If anything, a divergence can be observed.

7 Conclusions

The introduction of the euro was expected to cause product prices in the emerging monetary union to converge. Based on an extremely comprehensive and precise scanner database which represents 90% of all sales in 17 European countries over the period from 1995 to 2005, it can be shown that quality-adjusted washing machine prices did not exhibit any tendency to converge across EMU members. Moreover, a convergence cluster analysis cannot identify a convergence club which would comprise a larger subgroup of EMU countries and, at the same time, exclude the non-EMU countries in the sample. Instead, the clusters that can be found are mostly rather small and are usually unrelated to EMU membership. This implies that, in the washing machine market, neither the introduction of the euro at the start of 1999 nor the euro cash changeover three years later have had a noticeable price convergence impact. If anything, prices have diverged since then. Given that washing machines – being highly tradable, highly traded and easily comparable internationally – are rather optimal candidates to find the expected effects, these results raise doubts whether any aggregate effect can have occurred at all.

In the course of the analysis, a hedonic price regression was performed which yields the development of average quality-adjusted relative prices for as many as 17 European countries. To my knowledge, the present study is thus the first that is able to provide such a precise and comprehensive international price comparison for a nearly complete product market in so many countries over a period of 11 years. Earlier findings of statistically and economically significant deviations from the Law of One Price are confirmed.

As a direction of further research, the causes of the observed relative price developments, notably the apparent divergence of prices, remain to be investigated. Equation (1) suggests some potential culprits. Over most of the time after EMU was established, energy prices increased. This may have raised trade costs. As a second possibility, distribution costs especially wages in the distribution sector could have diverged in the euro area. Finally, competition may have increased much more in some EMU member states than in others resulting in diverging mark-ups. Apart from the causes of relative price movements, a more detailed analysis of the effects of potential country-specific feature preferences and their development over time may be of interest.

In spite of the negative findings in the present study, one may still take heart from the results of the literature according to which deviations from the LOP are much smaller in long-established monetary unions than in more recently founded ones. Although the observation period of seven years since the euro introduction (and four since the euro cash changeover) in the present study is quite substantial, it may still not be long enough to bring the expected price convergence effect forward. At least in such a case, however, a more thorough theoretical understanding of the mechanisms that relate the establishment of a monetary union to a firm's pricing behaviour would be desirable.

Table 1a:
Weighted hedonic regression of net log washing machine prices; sample 1

	Category	Coefficient	t
Constant term		5.72	1096.28
Load capacity in kg		.0523	80.84
Spinning speed (revolutions per min)		.000654	484.29
Degree of automation and	semi-automatic, no dryer	-1.122	-152.01
presence of drying function	washdryer	.261	218.82
(base: fully automatic, no dryer)	unknown	.186	7.22
Loading direction	toploading	.147	189.24
(base: frontloading)	unknown	.125	2.97
Construction type	built in/under	.317	120.61
(base: freestanding)	unknown	.0058	.58
Brand dummies	*p*-value[F(450;326638)]:		0.0000
Country-time dummies	base: Italy, 2001:2, each *p*-value (for given *i* or *t*):		0.0000
R^2			87.5 %
Number of observations			327,583

Sample 1: Four-monthly data for 1995:1-2005:3; Countries included: Austria, Belgium (since 1997:1), Czech Republic, Denmark (since 2001:1), Finland (since 2003:1), France, Germany, Greece (since 1999:1), Hungary, Italy, Netherlands, Poland, Portugal (since 1998:1), Sweden (since 1997:1), Slovak Republic, United Kingdom; *p*-values for the significance of country-time dummies refer to F-tests on all dummies for a given country *i* or for a given period *t*.

Table 1b:
Weighted hedonic regression of net log washing machine prices; sample 2

	Category	Coefficient	t
Constant term		5.34	898.33
Depth in cm		-.00777	-96.17
Load capacity in kg		.0876	135.74
Spinning speed (revolutions per min)		.000542	370.14
Water consumption (in litres)		-.00237	-80.66
Drum/tub type	single tub	-.0571	-12.00
(base: drum type)	twin tub	-.106	-2.09
	unknown	.249	1.90
Degree of automation	semi-automatic	-.891	-20.81
(base: fully automatic)	unknown	-.228	-1.77
Loading direction	toploading	.209	242.12
(base: frontloading)	unknown	.161	6.51
Presence of drying function	yes	.313	249.93
(base: no)	unknown	.210	16.13
Tub material	enamel	-.00512	-2.24
(base: stainless steel)	plastic	-.0145	-20.95
	unknown	-.0144	-16.08
Construction type	built in/under	.353	136.85
(base: freestanding)	unknown	.223	14.11
Presence of start delay function	yes	.0970	137.05
(base: no)	unknown	.0310	26.74
Presence of remaining time display	no	-.0104	-11.29
(base: unknown)	yes	.0274	22.70
Protection against water damage	no	-.00831	-8.04
(base: unknown)	yes	.0190	19.75
Brand dummies	*p*-value[F(292;336409)]:		0.0000
Country-time dummies	base: Italy, 2005:5, each *p*-value (for given *i* or *t*):		0.0000
R^2			87.3 %
Number of observations			337,313

Sample 2: Two-monthly data for 2000:1-2005:6; Countries included: Austria, Belgium, Czech Republic, Denmark (since 2001:1), Finland (since 2003:1), France, Germany, Greece, Hungary, Italy, Netherlands, Poland, Portugal, Sweden, Slovak Republic, United Kingdom; *p*-values for the significance of country-time dummies refer to F-tests on all dummies for a given country *i* or for a given period *t*.

Table 2a:
Phillips/Sul (2007) test on subgroup price convergence; sample 1 since 1999

Subgroup	t
Cluster 1: Greece, Italy	1.81
Cluster 2: Spain, France	-0.15
Cluster 3: Belgium, Portugal, Sweden, Netherlands, Slovak Republic	1.67
Cluster 4: Czech Republic, Poland, Austria	2.52
Cluster 5: UK, Germany, Hungary	4.44

Sample 1: Four-monthly data for 1999:1-2005:3; column t provides t-values of *b* estimates in equation (4) based on Newey-West standard errors. In table A4 in the appendix, the identification procedure for potential clusters is explained exemplarily for sample 2 (see also table 2c). The one-sided test rejects the null hypothesis of club convergence if t < -1.65.

Table 2b:
Phillips/Sul (2007) test on subgroup price convergence; sample 1 since 1997

Subgroup	t
Italy, Spain	-2.81
Cluster 1: Spain, France	1.09
Cluster 2: Belgium, Sweden, Netherlands	12.25
Cluster 3: Czech Republic, Poland, Slovak Republic, Austria, UK, Germany	1.73
Residual: Hungary	

Sample 1: Four-monthly data for 1997:1-2005:3; column t as in table 2a.

Table 2c: Phillips/Sul (2007) test on subgroup price convergence; sample 2

Subgroup	t
Greece, Italy	-3.58
Italy, Spain	-9.10
Spain, France	-2.94
Cluster 1: France, Sweden, Belgium, Portugal	1.41
Netherlands, Austria	-13.48
Cluster 2: Austria, UK, Slovak Republic, Czech Republic, Germany, Poland	3.54
Residual: Hungary	

Sample 2: Two-monthly data for 2000:1-2005:6; column t provides t-values of *b* estimates in equation (4) based on Newey-West standard errors. It combines columns 2 and 8 of table A4 in the appendix, where the identification procedure for potential clusters is explained exemplarily. The one-sided test rejects the null hypothesis of club convergence if t < -1.65.

Table 3a: MHDF and PCSE panel unit root tests; sample 1 since 1999

	Full sample: N = 14				EMU countries: N = 8			
	Base country: IT		Base country: FR		Base country: IT		Base country: FR	
Lags	MHDF	PCSE	MHDF	PCSE	MHDF	PCSE	MHDF	PCSE
1	0.53	-0.05	-1.55*	-1.47*	0.95	0.91	0.28	0.20
2	1.35	0.05	-0.97	-0.83	1.42	0.77	1.18	0.82
3	0.94	0.09	-0.95	-0.86	4.80	2.20	1.54	0.90

Sample 1: Four-monthly data for 1999:1-2005:3, which excludes Denmark and Finland; significant at the *** 1% level, ** 5% level, * 10% level. Column "lags" indicates the number of lags in the test equation.

Table 3b: MHDF and PCSE panel unit root tests; sample 1 since 1997

	Full sample: N = 12				EMU countries: N = 6			
	Base country: IT		Base country: FR		Base country: IT		Base country: FR	
Lags	MHDF	PCSE	MHDF	PCSE	MHDF	PCSE	MHDF	PCSE
1	-0.13	0.35	-1.09	-1.03	0.74	1.27	0.74	0.87
2	-0.02	0.29	-0.53	-0.52	0.36	0.50	1.27	1.44
3	0.14	0.15	-0.39	-0.40	-0.55	-0.65	1.00	1.31

Sample 1: Four-monthly data for 1997:1-2005:3, which excludes Portugal, Greece, Denmark and Finland; significant at the *** 1% level, ** 5% level, * 10% level. Column "lags" indicates the number of lags in the test equation.

Table 3c: MHDF and PCSE panel unit root tests; sample 2

	Full sample: N = 14				EMU countries: N = 8			
	Base country: IT		Base country: DE		Base country: IT		Base country: DE	
Lags	MHDF	PCSE	MHDF	PCSE	MHDF	PCSE	MHDF	PCSE
1	-0.88	-0.24	0.13	0.22	0.30	0.67	1.15	0.97
2	0.34	0.43	1.09	1.11	1.21	1.42	1.60	1.72
3	-1.10	-0.02	-0.68	0.12	-0.28	0.52	-0.24	0.76

Sample 2: Two-monthly data for 2000:1-2005:6, which excludes Denmark and Finland; significant at the *** 1% level, ** 5% level, * 10% level. Column "lags" indicates the number of lags in the test equation.

Table 4a: Standard F test on the equality of variances; sample 1

	Full sample		EMU countries	
H_A	1997:1-2005:3	1998:3-2005:3	1997:1-2005:3	1998:3-2005:3
convergence	0.56	0.87	0.23	0.23
divergence	1.79	1.16	4.33**	4.31**

Sample 1: Four-monthly data for 1995:1-2005:3; countries included: Austria (EMU), Belgium (EMU), Czech Republic, Denmark (data only for 2005:3), Finland (EMU; data only for 2005:3), France (EMU), Germany (EMU), Greece (EMU; data only for 2005:3), Hungary, Italy (EMU), Netherlands (EMU), Poland, Portugal (EMU; no data for 1997:1), Sweden, Slovak Republic, United Kingdom; significant at the *** 1% level, ** 5% level, * 10% level.

Table 4b: Standard F test on the equality of variances; sample 2

	Full sample		EMU countries	
H_A	2000:1-2005:6	2001:6-2005:6	2000:1-2005:6	2001:6-2005:6
convergence	0.74	0.73	0.21	0.31
divergence	1.34	1.36	4.73**	3.22*

Sample 2: Two-monthly data for 2000:1-2005:6; countries included: Austria (EMU), Belgium (EMU), Czech Republic, Denmark (no data for 2000:1), Finland (EMU; data only for 2005:6), France (EMU), Germany (EMU), Greece (EMU), Hungary, Italy (EMU), Netherlands (EMU), Poland, Portugal (EMU), Sweden, Slovak Republic, United Kingdom; significant at the *** 1% level, ** 5% level, * 10% level.

Figure 1a: Net washing machine prices in EMU countries in D-Mark; sample 1

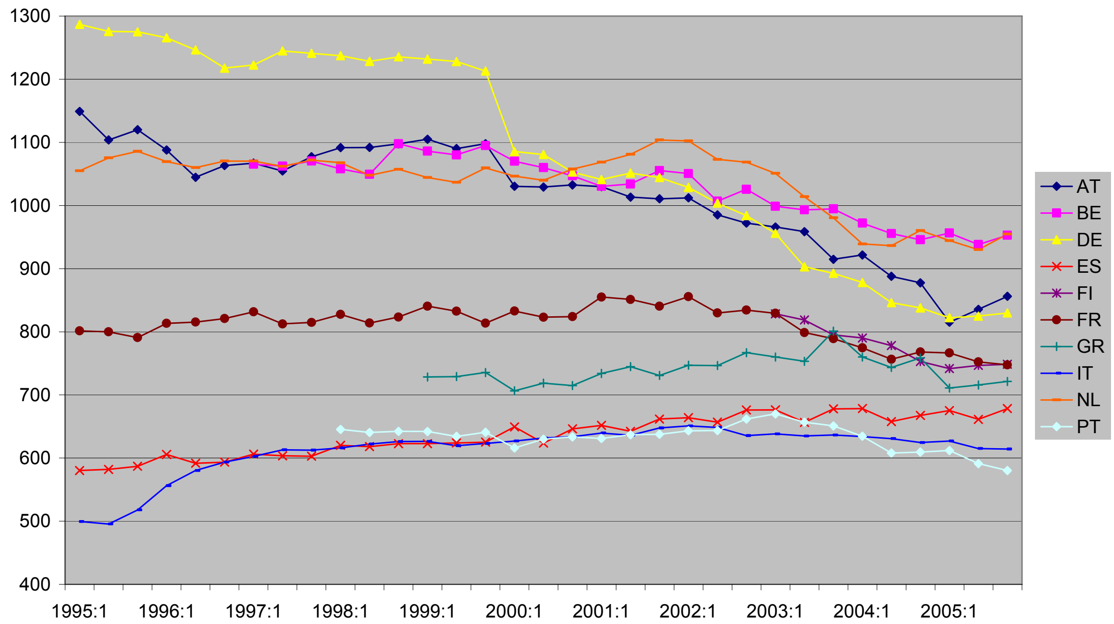
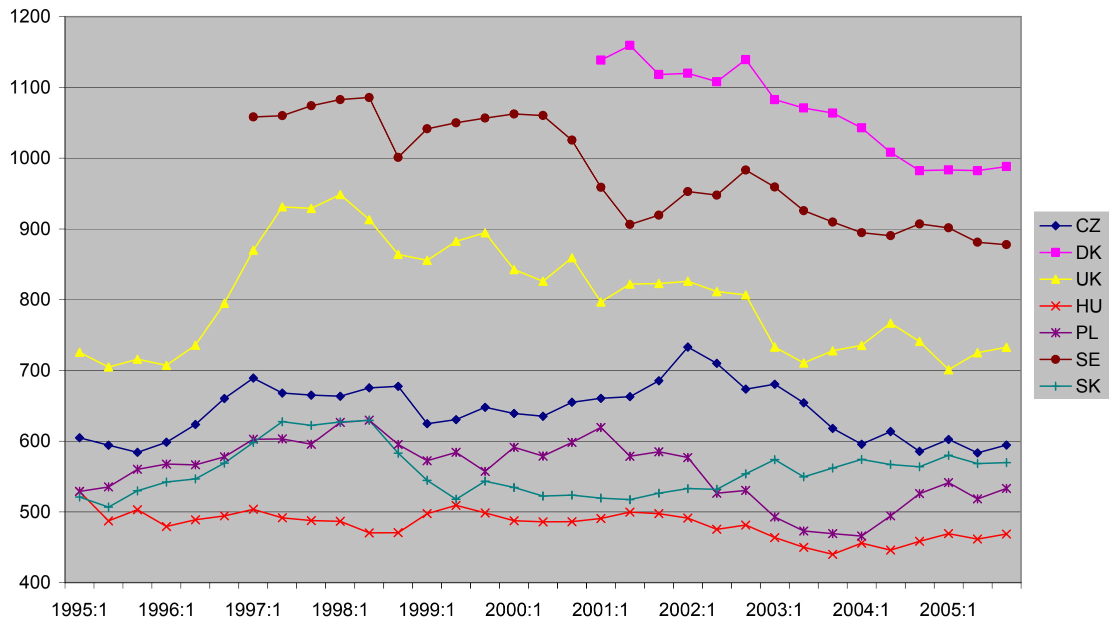


Figure 1b: Net washing machine prices in non-EMU countries in D-Mark; sample 1



Notes: Sample 1 consists of four-monthly data for 1995:1-2005:3; AT = Austria, BE = Belgium, CZ = Czech Republic, DE = Germany, DK = Denmark, ES = Spain, FI = Finland, FR = France, GR = Greece, HU = Hungary, IT = Italy, NL = Netherlands, PL = Poland, PT = Portugal, SE = Sweden, SK = Slovak Republic, UK = United Kingdom. Washing machines, whose loading capacity or spinning speed are unknown, are excluded from the sample.

Figure 2a: Quality-adjusted net price deviations of washing machines in EMU countries (sample 1; base: Italy, 2001:2)

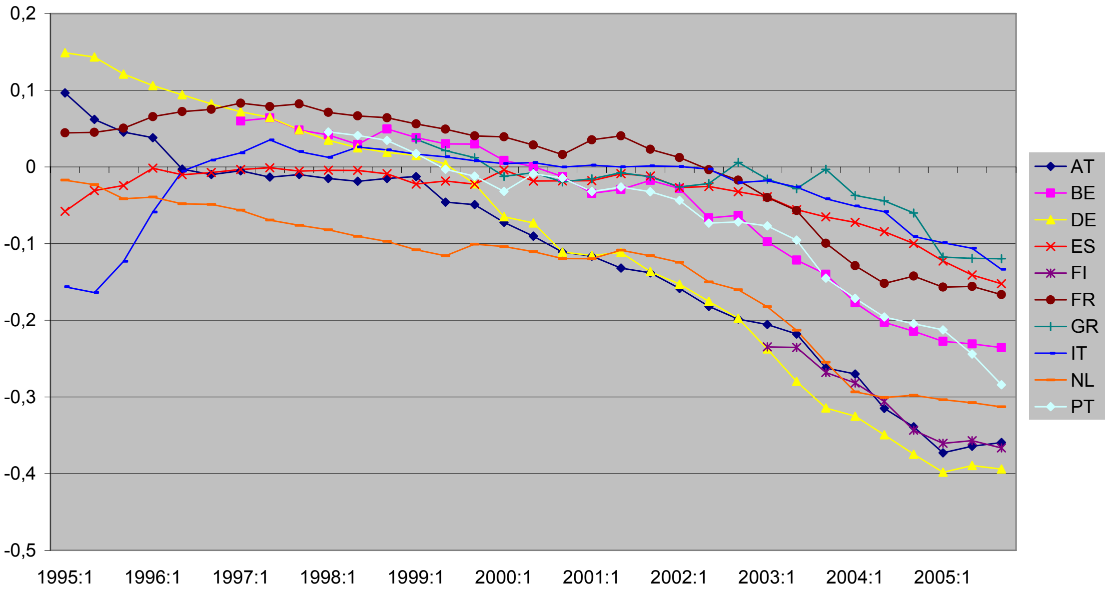
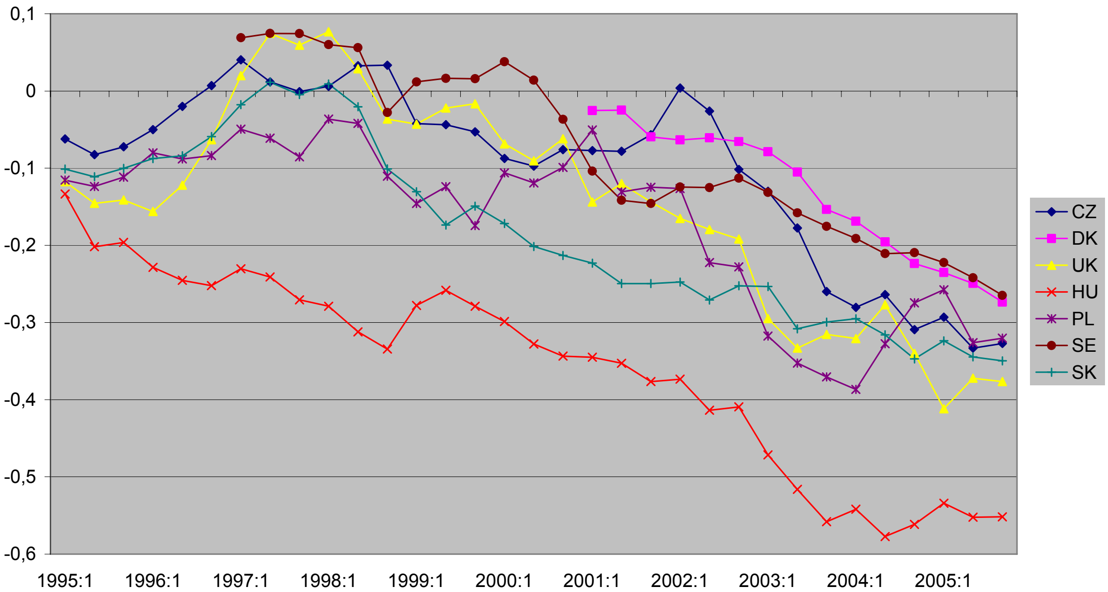


Figure 2b: Quality-adjusted net price deviations of washing machines in non-EMU countries (sample 1; base: Italy, 2001:2)



Notes: Time series are constructed from π_{it} estimates of the hedonic price regression equation (3). Sample 1 consists of four-monthly data for 1995:1-2005:3; AT = Austria, BE = Belgium, CZ = Czech Republic, DE = Germany, DK = Denmark, ES = Spain, FI = Finland, FR = France, GR = Greece, HU = Hungary, IT = Italy, NL = Netherlands, PL = Poland, PT = Portugal, SE = Sweden, SK = Slovak Republic, UK = United Kingdom.

Figure 3a: Quality-adjusted net price deviations of washing machines in EMU countries (sample 2; base: Italy, 2005:5)

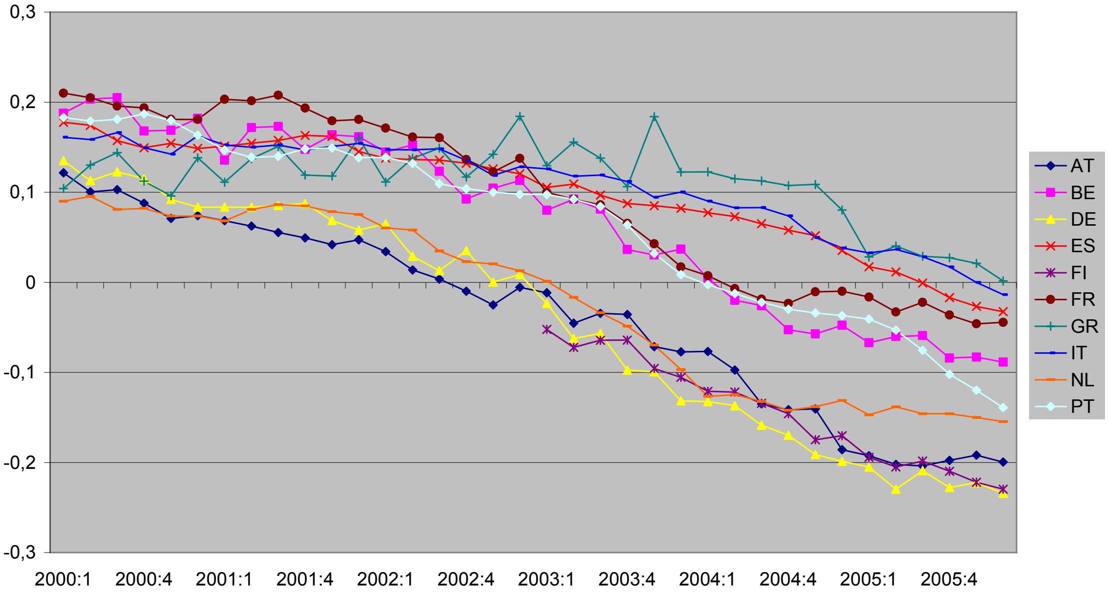
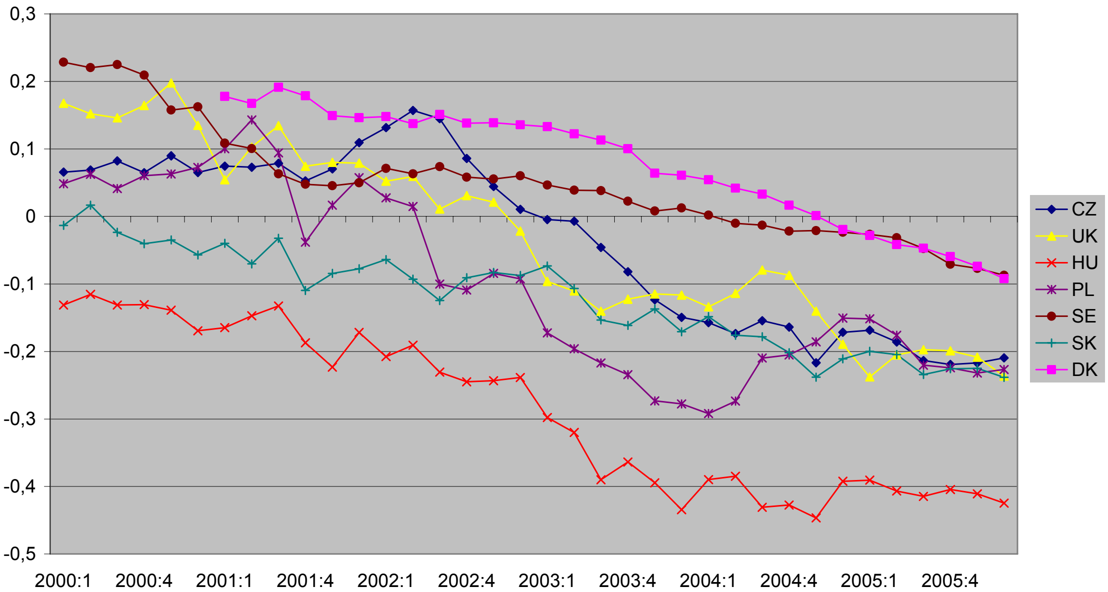


Figure 3b: Quality-adjusted net price deviations of washing machines in non-EMU countries (sample 2; base: Italy, 2005:5)



Notes: Time series are constructed from π_{it} estimates of the hedonic price regression equation (3). Sample 2 consists of two-monthly data for 2000:1-2005:6; AT = Austria, BE = Belgium, CZ = Czech Republic, DE = Germany, DK = Denmark, ES = Spain, FI = Finland, FR = France, GR = Greece, HU = Hungary, IT = Italy, NL = Netherlands, PL = Poland, PT = Portugal, SE = Sweden, SK = Slovak Republic, UK = United Kingdom.

Appendix

Appendix 1: Tables on the washing machine micro database

Table A1: The washing machine micro database, sample 1: four-monthly data since 1995

Country	Obs	Max models	Min models	Price (DM)	Sales	Period
AT	18,641	793	403	1206	118	95:1-05:3
BE	12,007	580	379	1236	183	97:1-05:3
CZ	15,073	787	156	776	143	95:1-05:3
DE	38,707	1430	861	1218	526	95:1-05:3
DK	6,393	595	244	1324	117	01:1-05:3
ES	37,190	1544	712	736	346	95:1-05:3
FI	4,445	597	332	943	98	03:1-05:3
FR	38,869	1540	941	972	529	95:1-05:3
GR	12,634	715	448	867	137	99:1-05:3
HU	10,655	802	103	597	188	95:1-05:3
IT	49,152	1787	1126	736	301	95:1-05:3
NL	20,339	759	442	1224	247	95:1-05:3
PL	17,023	1066	119	661	444	95:1-05:3
PT	14,234	796	332	744	125	98:1-05:3
SE	10,010	542	198	1206	131	97:1-05:3
SK	7,965	499	50	679	113	95:1-05:3
UK	17,304	852	326	935	1355	95:1-05:3
Total	330,641	1787	50	940	363	-

Column Obs = number of observations per country (= sum over time of the number of models recorded to be sold per four-month period), column Max (Min) models = maximum (minimum) number of models recorded to be sold per four-month period (= maximum (minimum) number of observations per four-month period), column Price (DM) = sales-weighted average washing machine price in D-Mark inclusive of VAT, column Sales = average number of sales units per model and period, column Period = observation period; both Price and Sales numbers are averaged over time and across models. AT = Austria, BE = Belgium, CZ = Czech Republic, DE = Germany, DK = Denmark, ES = Spain, FI = Finland, FR = France, GR = Greece, HU = Hungary, IT = Italy, NL = Netherlands, PL = Poland, PT = Portugal, SE = Sweden, SK = Slovak Republic, UK = United Kingdom. A quarter of the observations (81,471) predate the establishment of EMU on 1 January 1999 and 52% (171,752) predate the euro cash changeover of 1 January 2002.

Table A2: The washing machine micro database, sample 2: two-monthly data since 2000

Country	Obs	Max models	Min models	Price (EUR)	Sales	Period
AT	20,739	684	482	584	64	00:1-05:6[1]
BE	14,354	498	301	619	107	00:1-05:6
CZ	17,872	702	317	394	80	00:1-05:6
DE	40,963	1267	1030	564	324	00:1-05:6
DK	12,244	578	444	678	61	01:1-05:6[2]
ES	41,591	1459	870	388	192	00:1-05:6
FI	7,695	527	280	482	56	03:1-05:6
FR	38,172	1444	839	492	316	00:1-05:6
GR	20,793	622	493	444	73	00:1-05:6[3]
HU	14,426	754	208	300	92	00:1-05:6
IT	51,549	1550	1228	388	168	00:1-05:6[4]
NL	21,874	682	532	619	139	00:1-05:6
PL	23,141	993	371	325	209	00:1-05:6
PT	20,887	746	326	380	68	00:1-05:6
SE	14,815	525	449	596	66	00:1-05:6[2]
SK	9,808	447	153	340	58	00:1-05:6
UK	20,968	752	421	465	744	00:1-05:6
Total	391,891	1550	153	469	196	-

Column Obs = number of observations per country (= sum over time of the number of models recorded to be sold per two-month period), column Max (Min) models = maximum (minimum) number of models recorded to be sold per two-month period (= maximum (minimum) number of observations per two-month period), column Price (EUR) = sales-weighted average washing machine price in euro inclusive of VAT, column Sales = average number of sales units per model and period, column Period = observation period; both Price and Sales numbers are averaged over time and across models. AT = Austria, BE = Belgium, CZ = Czech Republic, DE = Germany, DK = Denmark, ES = Spain, FI = Finland, FR = France, GR = Greece, HU = Hungary, IT = Italy, NL = Netherlands, PL = Poland, PT = Portugal, SE = Sweden, SK = Slovak Republic, UK = United Kingdom; in some cases, earlier data available only in a four-monthly frequency; this applies to [1]January-April 2000 in Austria, [2]all data until the end of 2003 in Denmark and Sweden, [3]all data until August 2003 in Greece, and [4]all data until April 2001 in Italy; four-monthly data interpolated under transmission of seasonal patterns observed in two-monthly data; interpolated data ignored in columns Max models and Min models. 29% of the observations (112,849) predate the euro cash changeover.

Appendix 2: Does the use of a micro database make a difference?

An important reason for using a washing machine micro database on prices (and quantities sold) is the expectation that the extensive coverage of this particular market provides additional information which would be unavailable from other sources. National statistical agencies are also collecting washing machine prices, although much more selectively, covering only some types sold in some shops in some cities. If the collected prices meet the intention of being representative, they should provide a similar picture as aggregates obtained from micro sources. A comparison between the micro data used here and Eurostat data, which is widely used in studies on price convergence (see eg Allington et al, 2005, or Wolszczak-Derlacz, 2006), gives an indication of the similarity of the information content.

Eurostat data comprises comparative price levels for narrow product groups (basic headings) in an annual frequency, one of which is "washing machines, dryers and dishwashers". Given that the weight of washing machines in this product group should be large and that there is no obvious reason why the cross-country price deviation of dryers or dishwashers should differ considerably from that of washing machines, one might expect a high positive correlation between comparative price levels for this basic heading and methodologically corresponding series from our micro database.

Originally, the Eurostat comparative price levels are scaled to the geometric mean of the EU15. To allow for comparability, they have been rescaled to the geometric mean of those EMU countries that are included in the micro database. A methodologically comparative measure can be obtained from the micro database if the hedonic regression (3) is re-estimated using washing machine prices inclusive of VAT, $P_{V,it}$, and the resulting average quality-adjusted price premia, $\hat{\pi}_{V,it}$ are transformed as

$$\tilde{\pi}_{V,it} = 100 \cdot \exp\left(\hat{\pi}_{V,it} - \frac{1}{N} \sum_{i=1}^{N} \hat{\pi}_{V,it} \right). \tag{A1}$$

Pairwise correlation coefficients have been computed between these values and the rescaled Eurostat comparative price levels for the period 1995-2004, each in levels and differences. A one-sided test on the significance of the correlation coefficient against the alternative of positive correlation has been performed. The results are shown in table A3.[13] First, in most of the cases, the correlation coefficients are significantly positive. However, the existence of some significant positive correlation may be interpreted as a minimum requirement for two series which are supposed to reflect nearly the same subject, such that a 1% significance level may be adequate in this case. Second, if the 2004 results are ignored, because they are dominated by an extreme movement of the Eurostat comparative price level for the Netherlands, the correlation between the change in the relative prices is larger and meets higher significance levels than the correlation between relative price levels. With the initially mentioned caveat in mind, the low average correlation coefficients falling short of 0.5 for both comparative price levels and their differences might indicate problems with the representativeness of the Eurostat data for this basic heading. This may be one reason for the discrepancy between the rejection of price convergence in the present study and the results of Allington et al (2005), who chose exactly this product group for an illustration of price convergence in the EMU by highlighting the corresponding result of a "decline in [the] coefficient of variation of prices in the euro zone from 20 percent in 1999 to 9 percent in 2002".

Table A3: Test on positive correlation between washing machine related prices from the micro database and from Eurostat

	Comparative price levels	Differences
1995	0.97***	-
1996	0.87***	0.91***
1997	0.63**	0.90***
1998	0.46*	0.55**
1999	0.10	0.27
2000	0.36*	0.38*
2001	0.43**	0.72***
2002	0.37*	0.62***
2003	0.43**	0.83***
2004	0.75***	0.22
1995-2004	0.41***	0.36***

Countries included: Austria, Belgium (since 1997), Czech Republic (since 1999), Denmark (since 2001), Finland (since 2003), France, Germany, Greece (since 1999), Hungary (since 1999), Italy, Netherlands, Poland (since 1999), Portugal (since 1998), Spain, Sweden (since 1997), Slovak Republic (since 1999), United Kingdom; significant at the *** 1% level, ** 5% level, * 10% level.

[13] Log comparative price levels have been tested for pairwise correlation in the same manner. They yield very similar results.

Appendix 3: Application of the Phillips/Sul (2007) algorithm for the identification of price convergence clusters: an example

This appendix focuses on the exemplary application of the clustering algorithm to the specific case of washing machine prices considered in the paper as sample 2 (cf. table 2c). For a more formal description of the algorithm, cf Phillips/Sul (2007), p 1800-1801.

Table A4: Phillips/Sul (2007) test on subgroup price convergence: identification of clusters

1	2	3	4	5	6	7	8	9
GR								
IT	-3.58	-60.14						
ES	-9.10	-41.93						
FR	-2.94	-29.13						
SE			3.69				1.41	-9.44
BE			3.87					
PT			1.41	1.41				
NL			-46.31	-49.64				
AT	-13.48	-6.66		-17.88				
UK				-115.38	-1.48			
SK				-7.07	6.17		3.54	
CZ				-13.69	5.79			
DE				-28.94	6.84			
PL				-8.69	3.54	3.54		
HU				-33.77	-6.66	-7.12		

Sample 2: Two-monthly data for 2000:1-2005:6; AT = Austria, BE = Belgium, CZ = Czech Republic, DE = Germany, ES = Spain, FR = France, GR = Greece, HU = Hungary, IT = Italy, NL = Netherlands, PL = Poland, PT = Portugal, SE = Sweden, SK = Slovak Republic, UK = United Kingdom; columns 2-9 provide t-values of *b* estimates in equation (4) based on Newey-West standard errors; critical values: -1.65 in columns 1-4, 6, 8-9, and 0 in columns 5 and 7. Circled numbers indicate the course of the testing procedure.

The first step of the algorithm involves ordering the price series of individual countries according to the last observation, X_{iT}. Column 1 of table A4 displays the countries included in the 2000:1-2005:6 sample in the resulting order with Greece reporting the most expensive washing machines in 2005:6 and Hungary the cheapest. In the next step, a core group for a convergence cluster needs to be identified. For this purpose, the log t test is applied first to the subgroup of the two most expensive countries, Greece and Italy. Column 2 shows the results of such tests in the row of the second of such two-country subgroups. Given a critical value of -1.65, the null hypothesis that Greece and Italy belong to the core of a common cluster is rejected with a computed t-value of -3.58. Greece is thus separated as not belonging to any price convergence cluster. Column 3 shows the result of log t tests on the hypothesis that the complementary set of countries, in the present case Italy to Hungary, constitutes a cluster. This is firmly rejected.

Step 2 of the algorithm is then repeated for the second most expensive country, Italy, and the third one, Spain. Both of them are found to be isolated in the same way as Greece. The hypothesis that France and Sweden belong to the core group of a common cluster, however, cannot be rejected, which is the reason for showing the corresponding log t test result as the first entry in a separate column, column 4. In such a case, the algorithm cumulatively adds further countries until the log t test for the whole subgroup is rejected. In the present case, the first rejection occurs with the addition of the Netherlands. Then, the maximum of the computed t-values in column 4 identifies the core group, which is France, Sweden and Belgium.

In step 3 of the algorithm, log t tests are applied to the core group plus each of the remaining countries added one at a time. Using Monte Carlo studies, Phillips/Sul (2007) have demonstrated that it is preferable to add a country to the core cluster if the corresponding result exceeds a critical value of 0. Column 5 shows that only Portugal fulfills this criterion. A log t test on all of the countries of the proposed cluster confirms, as is shown in column 8, that price convergence cannot be rejected for this subgroup.[14] Column 9 demonstrates that the set of remaining countries does not constitute a convergence cluster. The last entry in column 2 suggests that the Netherlands do not belong to any convergence subgroup. The series of countries from Austria to Poland, however, forms a second multi-country cluster as is shown in columns 6 (step 2 as in column 4), 7 (step 3 as in column 5) and 8.

[14] In the present case, this test is actually redundant since it has been performed already in the course of step 2 as is shown in column 4 for the cheapest country of the cluster, Portugal. The redundancy stems from the fact that, in step 3, only consecutive countries have been assigned to the cluster. However, this is not a necessary outcome of the algorithm. Nevertheless, a similar redundancy is found for the second multi-country cluster in column 7 and, for both clusters, in column 8.

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