The Law of One Price and Its Violation: An Update on Empirical Advances

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Abstract

A monetary policy aiming to achieve some desirable macroeconomic objectives may be ineffective to some degree when the highly warranted Law of One Price (LOP) operation is violated. This essentialises identification of the potential barriers to price convergence in different contexts to maximize effectiveness of the monetary policies. With this end in view this study carries out a comprehensive review of the existing literature regarding the LOP and the half-life of the price convergence. The existing empirical evidences find that the prices tend to converge in most cases, and the barriers to and the speed of the price convergence depend on the specific contexts. Moreover, by using major Australian city-level daily petrol prices (an essential commodity) over a long period (2004-2020) and by employing unit root tests, this study estimates the half-life of the petrol prices across those cities. The findings are consistent with those of some existing studies.

Keywords: law of one price, price dispersion, half-life, unit root, convergence

JEL: E20, E30, E31, F20, F40

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1. Introduction

Theoretically, the LOP hypothesizes that in an efficient market the prices of the same basket of goods in two different locations may not be equal in the short-run in terms of a common currency, but they should be equal in the long run. It is because, such a market is well-integrated and its economic policies are highly effective. However, the degree of convergence of prices of goods and services across a small national economy is likely to be higher than that of a large national economy possibly consisting of distinctive regional economies, because the same national economic policy is likely to yield asymmetric outcomes at regional levels. While some outcomes may be desirable, some may not be. The monetary policy, for example, is designed to influence consumption, saving and investment favourably leading to equitable resource utilization of regional economies and ultimate equalization of wages and prices across regional economies. However, differential rates of regional resource utilization may yield acute regional economic disparities. The emergence of a sharp regional economic inequality over a period may cause socio-political tensions among different regions of the country. If this is not addressed on time, it may eventually lead to separatist movements in some regions and eventual disintegration of the country. The solemn responsibility of the national government, therefore, is to harmonize resource utilization of regions with a view to produce balanced effects on regional economies. However, producing balanced outcomes for different regional economies with uniform national economic policies is a daunting challenge for any national government.

While the national economic policies influence the regional economies, external actors may also affect them. When some national economies under an economic bloc (e.g., European Union) or under a supranational body (e.g., World Trade Organization) are fully integrated, external shocks (positive or negative) are likely to destabilize the equilibrium for a while. However, in the efficient markets these shocks are expected to be disseminated smoothly and quickly across national economies leading to harmonization of their consumption, saving, investment, and hence

resource utilization. This may be ultimately translated into a single price (expressed in terms of a common currency) for the same goods and services across national economies. Under a fully integrated international economic environment external shocks may affect national economies when national economies are too small to influence the rest of the world economy. However, domestic shocks which originate from within heavy-weight national economies (e.g., the US and Chinese economies) may also affect rest of the world. Whatever be the direction of causality any shock irrespective of its origin is likely to be absorbed smoothly and quickly when a domestic economy or the international economy is fully integrated. This is reflected in the establishment of a single price for a product or a service within the domestic economy or across well-integrated national economies. If this does not take place, it implies that scarce economic resources are not optimally utilized in some regions leading to sub-optimal production of goods and services and hence a lower-than-expected standard of living for their population. This necessitates identification of the barriers to convergence of prices within a domestic economy and across national economies and estimation of half-lives of price convergence.

Having realised the important role of price convergence in making the monetary policy most effective, researchers have been attempting to identify factors that are potential barriers to price convergence and hence contributors to an increase in the half-lives of goods and services. By carrying out a comprehensive review of the existing literature this study attempts to identify factors that are stumbling blocks to price convergence. As the researchers find different factors affecting the trend of the price convergence and half-life of goods and services, this study also estimates the trend of convergence of the petrol-price dispersion and half-life of the same across major Australian cities and finds that it varies from four to six months.

The following section discusses the methodological approaches being applied by various researchers. The third section sheds light on a variety of data used by researchers. The fourth section focuses on the critical evaluation of the existing literature concerning barriers to price convergence. The fifth section discusses estimates of half-life of goods and services. While the sixth section estimates the converging trend and half-life of the petrol-price dispersion across Australian States, the final section draws conclusions.

2. Methodological Differences

Researchers use the absolute LOP (Note 1) and the relative LOP (Note 2) to measure the extent of price convergence. Engel and Rogers (1996) use the standard deviation of relative prices to measure the extent of price convergence. They opine that when price differences of each product group across cities/regions/countries (we use locations now on) are less than the price differences of all products in each location, the relative LOP holds. Alternatively, the relative LOP holds when the ratio between the variation in prices of all products in the same location (the numerator) and that of the same product across locations (denominator) in the following equation 1 (i.e., r_j) is greater than unity:

$$r_j = \frac{\frac{1}{K-1}\sum_{l=1,l\neq j}^{K} sd(\Delta p^i_{j,t} - \Delta p^i_{l,t})}{\frac{1}{N-1}\sum_{m=1,m\neq i}^{N} sd(\Delta p^i_{j,t} - \Delta p^m_{j,t})} \quad (1)$$

In the equation (1) the denominator can be smaller than the numerator under the following three conditions: (a) The difference between the prices of the j[th] product group in two locations is small; (b) The price of the j[th] product group at the i[th] location is proportional to that of the j[th] product group at the m[th] location; and (c) The price of the j[th] product group at both locations hardly changes.

While Engel and Rogers (1996) use the standard deviation of relative prices to measure the extent of price convergence, some others (e.g., Levin and Lin, 1992; Maddla and Wu, 1999; Parsley and Wei, 2001; Ng and Perron, 2001; Im-Pesaran-Shin, 2003; and Isgut, 2004 and so on) use either an augmented Dickey-Fuller (ADF) unit root test or its modified versions to examine whether the relative price series (i.,e., $P_{ijt} = \ln\left(\frac{P_{ij,t}}{Pj,t}\right)$) are stationary or not.

As a result, the basic regression specification takes the following form:

$$\Delta p_{ij,t} = \alpha_{ij} + \beta_{ij} p_{ij,t-1} + \sum_{h-1}^{k} \gamma_{ijh} \Delta p_{ij,t-h} + \varepsilon_{ij,t} \quad (2)$$

where, Δ is the first difference operator; *i*, *j* and *t* stand for location, product group, and time, respectively; $p_{ijt} = \ln(\frac{P_{ij,t}}{\overline{P}_{j,t}})$ is defined as the price differential and P_{ijt} is the price index for product group *j* in location *i* at time *t*;

$\overline{P}_{j,t}$ is the national price index for product group *j*; $\varepsilon_{ij,t}$ is an identically independently distributed (i.i.d.) error term; and *k* is the maximum number of lags.

The ADF specifications include a constant term to capture location-specific fixed effects of some important factors (e.g., differences in taxes, income levels, transportation costs and wages). The test of the constant term reflects whether prices have been converging to absolute price parity (zero mean) or relative price parity (nonzero mean). The test of price convergence (the ADF unit root test) is simply a test whether β_{ij} in equation (2) is negative and statistically significant. It implies that prices have been converging over time. Its magnitude determines the speed of convergence. In contrast, if β_{ij} is positive and statistically significant, it signifies that the price differentials, p_{ijt}, have been non-stationary over time and hence price differentials exist. Given the negative and significant β_{ij} coefficient, the half-life (time required for closing half of the gap between two prices) of deviations is computed as: $\theta = \frac{\ln(0.5)}{\ln(1+\beta_{ij})}$. It is found that the aforementioned ADF test is biased towards rejecting the unit root hypothesis. This limitation is overcome by Levin and Lin (1992), who develops a method from a multivariate generalisation of the ADF test and provides a statistical concept of the panel unit root test. The Levin and Lin test applies the first-order autocorrelation for all equations. In contrast, Maddala and Wu (1999) as well as Im-Pesaran-Shin (2003) address this limitation by incorporating different autocorrelation coefficients for different panel members. Additionally, Maddala and Wu's (1999) panel unit root test is applicable to both balanced and unbalanced panel data. Studies further uncover that the order of the lag length is problematic in the case of the application of the ADF test. If the lag length is too small, the serial autocorrelation is not completely removed and hence the test is biased. In contrast, if the lag length is too large, the power of the test falls substantially. However, Ng and Perron (2001) suggest an optimal lag length for the ADF test that is capable of providing a stable size and minimum loss of power of the test. While the aforementioned studies use univariate test to identify trends of price convergence, Taylor et al. (2001) apply both multivariate and univariate tests to identify nonlinear mean-reversion in some series (e.g., real exchange rates) and demonstrate that multivariate tests are more powerful than univariate ones in rejecting a false null hypothesis. Moreover, multivariate tests allow treatment of the serial correlation of the AR(1) process. However, Lopez et al. (2005) find that their methodology is sensitive in selecting suboptimal lags in unit root tests. So, Taylor et al. (2001) prefer the median unbiased estimation method.

3. Differences in Data Being Used in the LOP Estimation

For empirical verification of LOP researchers use different data sets (Figure 1). The data set may be either aggregated or disaggregated at the national or regional levels. A disaggregated data set has a comparative advantage over an aggregated one, because the accuracy level of estimations is higher for the former than for the latter. They use either absolute or relative prices of inputs or outputs. Outputs are of two types - goods and services. While most services are non-tradeable, most goods are tradeable. Some use manufactured goods and some agricultural goods, while some use combinations of both. Some researchers use multiple goods, while some use single goods. Prices are expressed in terms of either local or foreign currencies with a view to making them comparable. Time horizons are either short-run or medium-run or long-run or some sort of their combination.

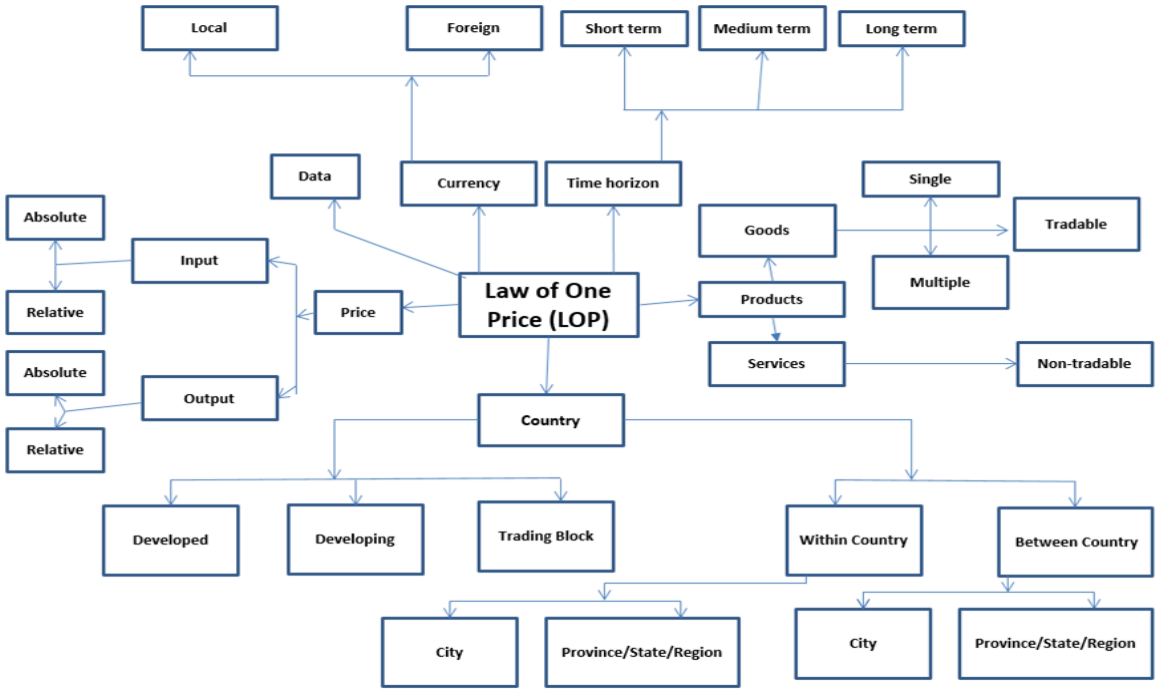

Figure 1. Various types of data being used in the LOP estimation (Source: The authors)

Some studies estimate the price convergence of a single or multiple goods and services in cities or regions or states/provinces (in the case of federal system) within a single country or among a number of neighbouring countries under either trading or non-trading blocks. The countries can have either developed or developing status. Figure 1 shows the identification of barriers to the LOP available in the existing studies. It is not only the differences in methodologies and data that may yield differential results, but results may also be different depending on the contextual factors (Figure 2).

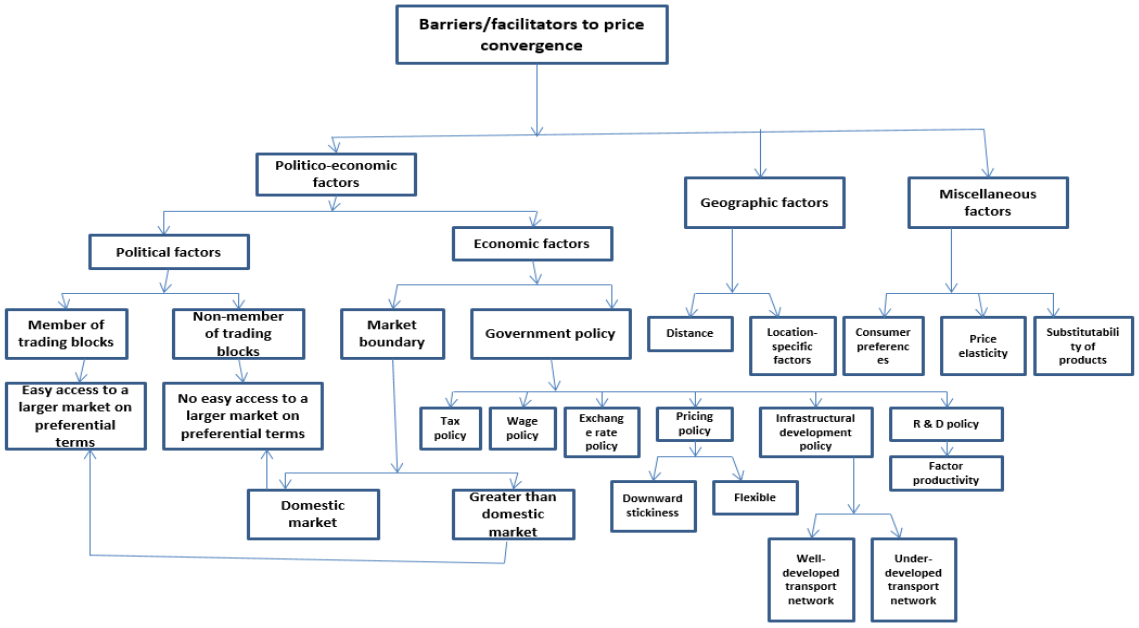

Figure 2. Contextual factors facilitating or inhibiting price convergence (Source: The authors)

4. Empirical Findings Regarding Barriers/Facilitators to the LOP

In the immediate previous two sections we focus on the differences in methodologies and data being used by researchers regarding estimation of the LOP and half-life of goods and services. As they use different methodologies and data, their findings are obviously different. The empirical evidence regarding the LOP are mixed. While the findings of some studies (e.g., Ceglowski, 2003; Crucini and Shintani, 2008; Fan and Wei, 2006; Goldberg and Verboven, 2005 and so on) support the LOP, those of some other studies (e.g., Asplund and Fribeerg, 2001; Cecchetti et al. 2002; Knetter and Slaughter, 2001; Sosvila-Rivero and Gil-Pareja, 2004 and so on) reject it.

Since 1980s onward globalization has been playing an important role in reducing price dispersion of goods and services across countries. However, tradability and non-tradability of consumer goods and services are some key factors in determining speed of price convergence within a country or across countries. By analysing highly traded US, German, Canadian and Japanese exportable goods, Isard (1977) finds a large and persistent deviation from the LOP. Similarly, Richardson (1978) draws the same kind of conclusion by examining 22 disaggregated commodity groups for the US and Canada. In addition, by analysing three tradable products, Giovannini (1988) opines that price differentials exist not only for sophisticated manufacturing products, but also for more disaggregated commodities (e.g., ball bearings, screws, nuts, and bolts). Ratfai (2006) finds a slower price convergence speed for non-tradable goods than for tradable food items. He suggests that the degree of persistence is related to the mean and volatility in price inflation.

While Isard (1977) and Richardson (1978) focus on the speed of price convergence by distinguishing goods into tradable and non-tradable, Rogers and Jenkins (1995) identify sluggish price adjustment as a potential barrier to the LOP. By applying the ADF test and cointegration test for 54 disaggregated goods and services for eleven OECD countries, they find that even for traded goods the LOP fails to hold in most cases. In the course of examining the validity of the LOP for both tradable and non-tradable goods in the US and Canada, Engel and Rogers (1996) find that the LOP deviation exists not only for inter-country city pairs, but also for intra-country city pairs. Although there is a violation of the LOP in both countries, price volatility in those countries is not symmetrical. The intra-US city pairs have higher price volatility than the intra-Canadian city pairs do.

Additionally, Rogers (2001, 2007) demonstrates that the convergence speed of prices of tradable goods is faster than that of non-tradable goods in the euro area, and the speed is similar to that of US cities. Maier and Cavelaars (2004) find that the price convergence occurs considerably faster for tradable than for non-tradable goods in united Germany following reunification. Using a richer dataset for OECD countries and 195 internationally comparable products over 1980-1996 periods, Egger et al. (2009) observe a significant σ-convergence in the majority of the OECD countries, specifically for tradable goods, provided that permanent and country-specific deviations from the LOP are controlled. The corresponding half-lives of LOP deviations turn out to be much higher for non-tradable than tradable goods. Parsley and Wei (1996) distinguished goods into perishable and non-perishable, because the prices of the former goods are less likely to converge than those of the latter. They find substantial differences in the trends of price convergence between perishable and non-perishable goods across US cities.

While the aforementioned studies deal with price convergence of mostly non-standard tradable and non-tradable goods in the US, Canada and the OECD countries, Parsley and Wei (2008) conduct a unique study of price convergence of a highly standard food item (i.e., Big Mac Meals and its tradable and non-tradable ingredients) in the case of Euro Zone. Before creation of the Euro Zone the average (weighted) price dispersion of Big Mac Meals and its constituents were lower in the Euro Zone than in the non-Euro Zone. By using 'difference-in-difference' specification and a three-dimensional panel data set of prices they find that creation of the Euro Zone caused a fall in the average (weighted) price dispersion since September 2003 in the Euro Zone. Though in the non-Euro Zone they were higher than they were in the Euro Zone, they were falling concomitantly as well. It may be mentioned that before the Euro Zone was created the average (weighted) price dispersion was lower for tradable ingredients than for non-tradable ones, but the average (weighted) price dispersion for non-tradable ingredients was falling more rapidly than that of tradable ingredients in the post-Euro Zone period.

The prices of a good between two locations may deviate to the extent of the transport cost. No arbitrage can eliminate it. Giver the distance the transport cost is expected to decline with the improvement of the infrastructure. In this context Engel and Rogers (1996 and 2001) and Rogoff (1996) argue that prices of a product being sold in two different locations should not differ by more than the cost of transportation given that transport and communication infrastructure of those locations are equally developed. Baffes (1991), therefore, argues that the LOP failure is mainly attributed to time-specific problems and transport cost. Parsley and Wei (1996) find a positive relationship between price dispersion and distance.

While the above studies focus on the price convergence of goods and services within the borders, Tomal and Gumieniak (2020) and Prado et. al. (2021) deal with the same of the factors of production, such land and labour. Using the beta- and sigma-convergence Tomal and Gumieniak (2020) find evidence of relative rather than absolute agricultural land prices convergence among Polish provinces in the long run (2001-2018). While the last year's inputs prices, per capita GDP and agricultural commodity prices accelerate price convergence, urbanization and interest rates decelerate the same. Prado et. al. (2021) investigate the real wage convergence of farm workers of Swedish counties and find that wage converged. The coefficient of variation declined from 28 percent to 4 percent in the long run (1757-1980). Alongside the mobility of labour, grain prices, immigration and unionization of industrial and agricultural labourers were drivers of wage convergence. While Tomal and Gumieniak (2020) and Prado et. al. (2021) view convergence phenomenon from a long run perspective, Gnat (2022) views the same from a very short run perspective, such as short-lived COVID-19. He tests his hypothesis that due to work-from-home arrangements priced of real estates are likely to converge between the main city called Szczecin of China and its surrounding satellite cities due to COVID-19. However, he finds the opposite.

The international border also creates an artificial barrier to free flow of goods and services. Engel and Rogers (2001) find that international border, distance and city-specific factors have significant effects on the price convergence across the European countries. The border effect is so large that the effects of nominal exchange rate volatility, language and geographic conditions together are unable to outweigh its effect. Beck and Weber (2001) point that even in a monetary union national borders and distance are important deterrents to price convergence. While Beck and Weber (2001) examine the effects of the monetary union on price volatility in constituent countries, Rogers and Smith (2001) explore the effects of international borders on price differentials among the neighbouring USA, Canada and Mexico. They observe that the border effect on US–Mexican relative prices is larger than that on US–Canadian prices. They further point that the border effect is not strictly a geographical phenomenon; it is rather related to the tax system, currency regime and other political factors. Beck (2003) observes that intra-continental markets are more integrated than inter-continental markets. It implies that presence of an ocean between two continents is likely to be an important barrier to market integration between them.

Borraz (2006) extends Rogers and Smith's (2001) analysis and discovers an existence of price variability between the US and Mexico. Although a significant part of this price variability between the US and Mexico can be explained by nominal exchange rate variability with sticky prices of final goods, the effect of the US–Mexico border on the price convergence is larger than that of the US–Canada border. Ceglowski (2003) finds that provincial borders have a substantial effect on inter-city price differentials in Canada, even after the effect of distance is controlled for. In contrast to Engel and Rogers (1996), the provincial border effects are found to be larger. Although most of the provincial border effects are large in absolute terms, they are insignificant in comparison to international border (US–Canada) effect as expected. However, the provincial border effects do not impede the price convergence. The inter-city price convergence rates are considerably faster than the international price convergence ones.

While above-mentioned studies use macro-level data, some studies (e.g., Atkeson and Burstein, 2008; Goldberg and Verboven, 2001; Gopinath et al., 2007) use micro-level data to compare price convergence across international borders. Broda and Weinstein (2008) use a unique barcode data for the US and Canada. Given that companies only use one barcode per product, comparison of the same barcode across countries provides an advantage of comparing the same goods internationally. It captures the border effect as well. Broda and Weinstein (2008) find that the LOP and the purchasing power parity (PPP) are held in their absolute forms across the border as well as within countries. Moreover, the negative effect of the distance on the price convergence is five to ten times larger in the case of the aggregate data than the barcode data.

The aforementioned studies (e.g., Atkeson and Burstein, 2008; Goldberg and Verboven, 2001; Gopinath et al., 2007) pose a challenging task of exploring price differentials using rarely available micro-level data. Some other studies (e.g., Allington et al., 2005; Foad, 2010; Sosvilla-Rivero and Gil-Pareja, 2004) use price indices of broader product categories within and across countries and estimate that both the European Economic Union and the euro increase the speed of price convergence. Foad (2010) estimates border effects on the price convergence in Europe before and after the formation of the euro over the 1995-2004 periods. His dataset consists of per diem rates broken down into 'lodging' and 'meals' in smaller and larger European countries before and after the Euro formation. His findings show that the euro reduced price dispersion across member countries, but the reduction in the scale of price dispersion was more among larger than among smaller countries. In fact, price dispersion did not fall in the case of smaller countries. The underlying reason is that before the euro smaller euro member countries tagged their exchange rates with larger euro member countries especially with Germany's, but larger countries set their exchange rates almost independently. Considering euro-adopted countries as a treatment group and a group of countries outside the

non-EMU countries as a control group, Allington et al. (2005) investigate comparative price indices for individual consumption expenditure in 200 product groups and show that the euro and the EMU increased market integration and reduced price dispersion significantly in common currency countries.

The dismantling of international borders may accelerate price convergence of goods and services, whereas the price rigidity may decelerate the same. Crucini et al. (2010) hypothesize that variations in LOP deviations would be lower for goods with infrequent price adjustment when distance is controlled. Using a Japanese data set they find strong evidence in favour of their hypothesis. However, Crucini and Smith (2016) find that effects of distance on the price convergence declined with an improvement in the transport and communication since the beginning of the 18th century. Likewise, Elberg (2016) uses a highly disaggregated dataset comprising weekly sampled store-level prices and find that sticky prices and geographical distance could explain a large fraction of the variability in the LOP deviations. However, the effect of sticky prices outweighs that of the distance. It may be mentioned that domestic prices may be resistant to the volatility of foreign exchanges (Engel and Rogers, 1996, Haskel and Wolf, 2001). In that case the LOP may violate in the short- and long-run for lack of complete pass-through of the volatility in foreign exchange rates (Feenstra and Kendall, 1997).

Though price in local currencies is found to have resisted the exchange rate volatility substantially (e.g., Feenstra and Kendall, 1997; Engel and Rogers, 2001 and Engel, 1993), being members of a monetary union is likely to lower price dispersion among member countries (e.g., EMU) than among non-member peer countries (e.g., OECD). Gil-Pareja and Sosvilla-Rivero (2004) investigate the export unit values (value of exports divided by the quantity) of 8-digit products of 7 European Union countries to OECD destinations over the 1988-2001 periods. They find that dispersion in export unit values is lower in the former group than their peers in the latter group. The underlying reason might be prevalence of more stable exchange rates among the European Union member countries than among the OECD countries. However, they find little evidence of converging trend in export unit values in the European Union member countries. It may imply that being a member of a monetary union is not a sufficient condition for converging export prices among member countries. Gil-Pareja and Sosvilla-Rivero (2004) include only OECD countries as destinations of exports of the EMU countries, whereas Knetter and Slaughter (2001) incorporate both developed and developing countries as destinations of the US and German exports over the 1973-1987 periods. Their findings suggest that European countries have been moving towards a single market due to, among others, declining price dispersion across European export destinations.

While differential exchange rates may be a cause of price dispersion among trading countries, a common currency (e.g., the euro in the European common market) is expected to accelerate market integration by increasing price transparency, reducing transaction costs and eliminating exchange rate fluctuations. Long before formation of the euro its proponents and opponents debated on potential benefits (e.g., lowering of prices following market integration) and costs (e.g., loss of control of an individual country on its money supply) of forming such a monetary union. In this context, shortly after the EMU Beck and Weber (2001) investigate the effect of the EMU on European goods market integration. They use both aggregated (1991-2002) and disaggregated (1995-2002) monthly CPI data for 81 cities of 7 European countries. They find that the euro has been propelling the European economic integration by substantially reducing cross-border relative price volatility. Nearly 80 to 90 percent of the initial relative price dispersion among the member countries was eliminated within the first year of the EMU. However, regarding elimination of the rest amount they prophesized that neither in the short run nor in the long run the EMU alone would be able to eliminate the entire cross-country relative price volatility. This prophecy subscribed to Engel and Rogers (2001) who demonstrate that despite more price transparency under a common monetary policy and complete absence of intra-EMU trade barriers European product markets were still segmented.

Goldberg and Verboven (2001) identify price elasticity differences in mark-ups, price inertia and import quota constraints as three major determinants of price differences across European countries. They argue that the EMU would be able to reduce it. Parsley and Wei (2001) observe that the European product market integration has been increasing over time and is inversely related to distance, exchange rate variation and tariff barriers. By investigating the European car market Goldberg and Verboven (2004) observe that both EMU and non-EMU countries have been experiencing a reduction in price dispersion after introduction of the euro in 1999 and the reduction rate has been higher in non-EMU countries since 2002. Since euro formation, price convergence has been increasing among European countries (Goldberg and Verboven, 2005); Gil-Pareja and Sosvilla-Rivero, 2008; Rogers, 2001 and 2007))

While the aforementioned studies (e.g., Goldberg and Verboven, 2001; Gil-Pareja and Sosvilla-Rivero, 2008; Rogers, 2001, 2007) credit the euro in reducing price dispersion, Faber and Stokman (2009) rebut that the price convergence in the EMU countries started long before in the 1960s when the EMU was non-existent and the trend of price

convergence throughout the 1990s was a continuation of the pre-existing trend. They identify some potential factors (e.g., indirect tax rate harmonisation, convergence of costs of non-tradable and tradable input costs) that were instrumental in this regard. This raises the question whether the formation of the EMU has accelerated the speed of price convergence among member countries. In this context Baye et al. (2006) examine the online-purchased-prices of 28 products which are mostly electronic. They find that the introduction of the euro has little effect on the speed of price convergence in the EMU member countries. By analysing a comprehensive dataset consisting of, among others, quality-adjusted washing machine prices Fischer (2012) concludes the same. Although a slight converging trend is observed, Fischer (2012) argues that it is least likely due to the EMU formation. Similarly, Imbs et al. (2010) analyse the raw prices and characteristics of television sets for EMU and non-EMU countries with a view to tracing back the sources of their price dispersion. They find that even for identical television sets price dispersion prevailed in both non-EMU and EMU countries. However, it was lower in the EMU countries than in non-EMU countries. They argue that the lower price dispersion in the EMU countries has little association with their common currency.

Goldberg and Verboven (2005), Gil-Pareja and Sosvilla-Rivero (2008) and Baye et al. (2006) focus on products belonging to a single sector, whereas Lutz (2004) and Engel and Rogers (2004) investigate the retail prices of multiple sectors. The latter studies find little or no effect of the euro on price convergence among member countries. Likewise, Engel and Rogers (2004) examine the consumer prices of 101 narrowly defined tradable and 38 non-tradable goods from eleven EMU and seven non-EMU countries. The non-EMU countries serve as a control group. Their findings suggest that the common currency was unable to strengthen the European market integration for multiple reasons (e.g., value-added tax, mark-up, wage bills and transportation costs and so on). Indeed, the considerable market integration has been occurring due to reduction in economic barriers.

So far, we have discussed the role of price stickiness, exchange rates and economic union in accelerating price convergence without any reference to the role of sellers in fixing prices. Sellers may rather set prices strategically targeting at the psychology of buyers to maximize their profits. According to this strategy called psychological pricing, sellers do not round up the price (e.g., $12.00) rather they set the price a little below it (e.g., $11.95) with a view to befool target buyers that the former price is too high, whereas the latter price is too low. The formation of the euro zone provides researchers an opportunity to test effectiveness of this strategy. Friberg and Matha (2004) examine price differentials of more than 100 products in different stores and find that sellers do not use psychological pricing strategy across the board; rather they use it for some selective products. They find that the psychological pricing and prices set in euro other than national currencies play a positive role in reducing price dispersion. Rounding prices do not have any important impact on reduction of price differentials. Their findings thus confirm a positive effect of the euro on the price convergence. While Friberg and Matha (2004) are concerned with identifying evidences of non-psychological price convergence, Dreger et al. (2008) explore effects of euro enlargement on the speed of price convergence and find it slower in comparatively low-income European countries in the presence of higher inflation rates. In contrast, using higher-income non-euro European countries as a control group and employing difference-in-difference estimation technique Ogrokhina (2015) find mixed results. Price differentials increase for some products (e.g., food, alcohol, and tobacco), whereas for majority of tradable goods the euro has insignificant effects. Understandably, a common currency is expected to add an extra momentum to existing converging trends of prices triggered by formation of the European Economic Union (EEU), but it does not. Her probable explanation is that transaction costs do not fall as much as they are expected. Secondly, prices did already converge to the minimum possible levels under the EEU and hence the euro is ineffective in reducing price differentials further.

The price differentials, among other factors, may persist due to differences in quality of products. The euro was expected to improve quality of products following increased competition among producers across the euro zone. Usually price differentials among different brands (e.g., LG, GE, Samsung, Bosch, Haier and so on) belonging to the same category products (e.g., refrigerator) are likely to reflect their qualitative differences. This made the use of highly disaggregated data necessary. While some studies (e.g., Rogers, 2004; Engel and Rogers, 2004 and Beck and Weber, 2001) use highly disaggregated data to estimate trends in price convergence of certain categories of goods, they fail to capture price differentials resulting from qualitative differences among different brands as well as among different kinds of the same brand (e.g., top-mount fridges, bottom-mount fridges, French-door fridges, side-by-side fridges, single-door fridges and so on). Each type could be further sub-classified (e.g., each type of freezer can have different capacity, such as 624lt, 676lt, 687lt and 696lt and so on). In order to address this important issue, Mejean and Schwellnus (2009) use extremely narrow product categories (8-digit classification level export items) being produced by the same company. This made it possible to compare intra-firm and inter-firm price differentials resulting from qualitative differences of products. Moreover, it was also possible to compare changing trends in the

average price of exports within and outside Europe. Their study reveals that large firms divide export markets strategically into larger and smaller sub-markets. They enter larger markets where fixed costs of entry are higher, and prices can be kept low by distributing a given price increase on a larger volume of export. This strategy restricts competition in larger markets and hence it also restricts price convergence. However, the international relative prices converge at 40 percent faster rate within the EU than outside the EU. Moreover, within-farm price convergence accounts for 60 percent reduction in the average relative price. The reduction in the intra-firm cost results from market segmentation through price discrimination, whereas the reduction in the inter-firm cost results from reduction in fixed entry cost. While larger firms segment export market by price discrimination, smaller firms follow non-discriminatory pricing policy across their export markets.

Alongside the differences in quality, the differences in inflation rates may contribute to price convergence or divergence across countries. Prior to formation of the euro (EMU), its member countries had differential inflation rates. The same trend was observed in East and West Germany prior to unification as United Germany. Two key factors underlying these inflation differentials were cyclical factors (e.g., business cycles and wage setting and so on) and structural factors (e.g., differences in the productivity between tradable and non-tradable sectors). This pre-existing inflation differential might lead to economic imbalances among member countries in absence of a monetary union. Maier and Cavelaars (2004) find that inflation rates in erstwhile East and West Germany converged asymmetrically following unification. The converging trend of the inflation rate in low-priced East Germany was higher than that in high-priced West Germany. Guerreiro et al. (2012)'s investigation into the inflation dynamics in euro member countries manifest similar trends. Lopez and Papell (2012) investigate inflation dynamics across twelve founding members of the euro zone (e.g., Austria, Belgium, Finland, France, Germany, Luxemburg and Netherlands) as benchmark, because they were comparatively low. They compared inflation rates of Greece and Spain with it and found them much higher than the benchmark ones.

We observe that the nature of products, price stickiness, exchange rates, economic and monetary union, strategic pricing and so on are likely to contribute positively or negatively to price convergence. Alongside them, the factor cost which constitutes a major component of the total cost of products and services may play an important role in this regard. This is because Heckscher-Ohlin's factor price equalization theorem predicts that when product prices of trading countries are equalized following free trade of products, their factor prices are necessarily equalized under certain assumptions (Note 3). As goods flow easily among countries of a trading bloc, factor prices of the manufacturing sector of the member countries are more likely to converge (Mokhtari and Rassekh, 1989). O'Rourke and Williamson (1992) find that the factor price equalization was the major source of equalization of product prices in the US and Western Europe, whereas Williamson et al. (1993) show that the real wage convergence between the UK and the US over the 1871-1910 period caused convergence in their commodity prices. As a result, there is a possibility of two-way causality. Kotlikoff et al. (1981) find converging trends in the wages in the manufacturing sector of the US, German, Japan and Korea relative to developed Western economies, whereas some other studies (e.g., Tovias, 1982) show that they converged over some periods and thereafter they started diverging. The aforementioned studies use simple statistical techniques. Moreover, they do not consider simultaneous relationship among prices of different countries. Considering empirical limitations (Note 4) of testing the factor price equalization theorem Jung and Doroodian (2000) test the factor price convergence theorem. They select wages of the manufacturing sector of 7 EC countries, the US and Canada, because they satisfy some necessary conditions (Note 5). Moreover, they use cointegration tests to determine long-run relationship and the error-correction model to test two-way causality among wages in different countries. Their findings show that labour costs in the manufacturing sector converged in the long run and they influenced one another. Free trade and immigration were likely drivers of this converging trend.

5. Half-life of Price Convergence

The immediate previous section identifies factors contributing to increasing or decreasing speed of price dispersion (dispersion from the initial price resulting from a unit shock to it). This section aims to review the time span (i.e., half-life) being required to close the price dispersion of goods and services by half as estimated by researchers. It is observed that wages and prices of products at the firm-level respond slowly to macroeconomic events. Researchers, therefore, try to find out its microeconomic foundations. They observe that some firms adjust their prices frequently, while others do not. This may be in response to the market demand and supply of their products. Firms may adjust prices as close to market equilibrium prices as possible. The monetary policy is, therefore, likely to become more effective if adjustment in prices is infrequent, less effective otherwise. In this context Blinder et al. (1998) compile firm-level prices through structured questionnaire and find that half-lives of product prices vary from two to six months. The reasons may be attributed to multiple factors, such as nominal contracting, implicit contracts, assessing

quality by prices, psychological pricing, pro-cyclical elasticity of demand, cost-based pricing, constant marginal cost, cost of adjusting prices, hierarchy, coordination failure, accumulation of inventories, non-price competition and so on (Blinder et al.,1998:295-314). While Blinder et al. (1998) use firm-level survey data, Bils and Klenow (2004) use product-level data. They collect frequencies of price adjustment of 350 categories of goods and services which covered 70 percent of total consumer spending in the US over the 1995-97 periods. They observe that prices of 50 percent of products were sticky for a period between 4.3 months and 5.5 months depending on product categories. This sort of price stickiness arose largely due to wage contracts.

Some studies (e.g., Cumby, 1996; Goldberg and Verboven, 2004) focus either on an individual good or on a subset of goods within the CPI basket. Goldberg and Verboven (2004) estimate the half-lives of relative price deviations of European automobiles and find that they vary from 1.3 years to 1.6 years depending on country-specific structural factors (e.g., differences in the price elasticity of demand, trade policies, local distribution costs and so on). Cumby (1996) find the half-life of international price deviations in McDonald's Big Mac hamburgers is about one year when non-zero mean deviations are accounted for. Either exchange rates or relative local currency prices adjust towards Big Mac parity.

By using quarterly prices of 51 individual goods in 48 US cities over the 1975-1992 period, Parsley and Wei (1996) find that the half-life of non-perishable goods is 5 quarters, perishable goods 4 quarters, and services 15 quarters. The half-lives of tradable goods (both perishable and non-perishable items) vary roughly from 4 to 5 quarters. While Goldberg and Verboven (2004) find that transport costs significantly hinder reduction of half-lives of many products, Parsley and Wei (1996) observe that it plays a little role in increasing the half-lives of many products. Using semi-annual retail prices of 45 consumer goods collected from 25 Canadian cities over the 1976-1993 periods Ceglowski (2003) finds that half-lives of consumer goods in cities within the Canadian international boundary are less than a year. The geographic distances between cities hindered the speed of price convergence and hence extended half-lives of products. The findings of Parsley and Wei (1996) and those of Ceglowski (2003) were, therefore, conflicting. However, the findings might be context dependent.

While Parsley and Wei (1996) estimate half-lives of fifty-one goods and services in forty-eight US cities over the 1975-1992 periods, Susanto et al. (2008) estimate half-lives of prices of 3 varieties (red, white, and yellow colour) of onions in ten North American (i.e., the US, Canada, and Mexico) city markets over the 1998-2006 periods. Susanto et al. (2008), therefore, expand the number of countries bonded by a free trade agreement, but reduce the number of goods to a single category (i.e., onion) with a special focus on its three major varieties. However, their periods of interest are non-overlapping which might make their results a bit incomparable. They run their fixed effect models with and without the time trend as well as with and without varieties of onions. They find that the half-lives of onion prices in New York and Dallas became shorter when the time trend is included, longer otherwise. Similarly, when onion varieties are included, half-lives become shorter, longer otherwise. However, the half-lives of onion prices are not significantly different across cities (New York and Dallas) within the same country. They change marginally when onion prices of different city markets are treated as benchmarks.

So far, we largely discuss estimation of half-lives of goods and services in a single country, such as the USA and its peers. When more than one country is involved, use of the purchasing power parity (PPP) is a more acceptable method of comparing prices of goods and services across countries. Analysing selected data (a micro-level panel data set (Note 6) for the 1990-2005 periods) collected by Economic Intelligence Unit's Worldwide Cost of Living Surveys Crucini and Shintani (2008) find that the half-life of deviations from the LOP for the median goods is 19 months for the OECD countries, 12 months for the developing countries and 18 months for the US cities. It is seen that price convergence of goods in the OECD and those in the US have similar half-lives. This might be due to similarity in their socioeconomic structures, openness of economics and so on. The usage of a large micro-level panel data is expected to give more precise estimates of half-lives of goods and services, but results obtained from usage of the PPP might suffer from some biases (e.g., inappropriate aggregation across 'heterogeneous coefficients, time aggregation of commodity prices and downward bias in estimation of dynamic lag coefficients) as mentioned by Choi et al. (2006). Since the PPP has implications for the real exchange rate Choi et al. (2006) account for those biases in their analysis of half-lives of CPI-based real exchange rates for 21 OECD countries over the 1973-2002 periods and find that the estimated half-life is 5.5 years. Though there is a stable relationship between the PPPs and real exchange rates in the long-run, this relationship might collapse in the short-run mainly due to sticky prices, non-tradability, and trade barriers and so on (Rogoff, 1996). From this phenomenon it is understandable that data sets that are involved with long-run periods are likely to yield more accurate estimates of the half-life of the PPP deviations than short-run ones. The time horizon being considered by Choi et al. (2006) is nearly 30 years. If it is considered a short-run period, some other studies (e.g., Frankel, 1986 and 1990; Abuaf and Jorion, 1990; Glen, 1992;

Diebold et al., 1991; Lothian and Taylor, 1996 and so on) include periods which might be considered very long-run periods.

Frankel's (1986 and 1990) data set consists of annual dollar-pound exchange rates and span over 160 years (1869-1984). He finds that the half-life of PPP deviations was 4.6 years. While Frankel's (1986 and 1990) study is concerned with two currencies (i.e., dollar and pound) over a period of 116 years, Abuaf and Jorion's (1990) study consists of currencies of 9 countries (i.e., the US, Canada, France, Germany, Italy, Japan, Netherlands, Switzerland and the UK) over a period of 82 years. Abuaf and Jorion's (1990) study analyzes two data sets: (i) a very long period: annual real exchange rates covering 73 years (1901-1972) which encapsulate periods covering the gold standard period (1900-14 and 1925-31), the flexible exchange rate period and a gold exchange rate period (1945-71); and (ii) a short period: monthly exchange rates covering the 1973-81 period which cover floating exchange rate regime. While the monthly real exchange rates over the 1973-87 periods produce the half-life of the PPP convergence between 3 and 5 years, the annual real exchange rates over the 1900-71 periods produce 3.3 years for the same.

Although most aforementioned studies use long-run time horizons and dynamic econometric techniques to estimate trends in price convergences and half-lives of deviations from the PPPs and real exchange rates, they suffer from some important limitations. In terms of length of periods the concerned time horizons are absolutely long-run, but the data is mostly yearly. The data sets, therefore, have low frequency. The dynamic econometric techniques being used in the analyses require high-frequency data. Therefore, trends in price convergences and half-lives of deviations from the PPPs and real exchange rates as estimated by most previous studies are not much reliable. In this context Diebold et al. (1991) generate 16 real exchange rates (10 using the wholesale price indices and six using the consumer price indices) for 6 countries (Belgium, France, Germany, Sweden, the UK, and the US). The shortest period is 74 years long and the longest one is 123 years long. They use a class of long memory models (autoregressive fractionally integrated moving average) that enables flexible parameterization of low-frequency data. They find that the PPP held in the long run for all 6 real exchange rates and the average half-life for shocks to PPP is about 3 years.

While Diebold et al. (1991) use a single real exchange rate series (dollar-pound) having 123 years length, Lothian and Taylor (1996) use two real exchange rate series (dollar-sterling and franc-sterling) spanning nearly two centuries (1791-1990). Moreover, the former uses a class of long-memory models, whereas the latter use simple stationary autoregressive models. Another point of departure of Lothian and Taylor (1996) from Diebold et al. (1991) is that Diebold et al. (1991)'s periods of interest consist of a mixture of various types of exchange rate regimes (Note 7), but Lothian and Taylor (1996)'s one is the pre-floating exchange rate regime. Additionally, Lothian and Taylor (1996) use pre-floating PPPs and exchange rate relationships to forecast degree of stability in the post-floating ones. Diebold et al. (1991)'s relationship is an average of differential relationships under different exchange rate regimes. This might not be helpful for designing effective monetary policy under a certain exchange rate regime. Lothian and Taylor (1996)'s approach might be helpful when associated countries switch from one sort of exchange rate regime to another. Lothian and Taylor (1996) find the exchange rates series slowly mean-reverting. The half-life for the franc-sterling series is 3 years and that of the dollar-sterling series is six years.

Diebold et al. (1991) find the half-life of the PPP deviations 3 years, whereas Lothian and Taylor (1996) estimate it 6 years. Though they use long-run period, their approaches are different. Since they use long periods, their periods have sub-periods dominated by either gold standard or flexible or fixed exchange rate regimes. Evidence suggest that the real exchange rate is more volatile under the flexible nominal exchange rate and the main driver of the volatility is the nominal exchange rate. The national price level is not as volatile as the nominal exchange rate. The changes in the nominal exchange rate have probably impacted the real or expected economic conditions. The speed of the PPP adjustments and hence half-life of PPP deviations are, therefore, different under different exchange rate regimes. Frankel and Rose (1995) argue that it is not the length of concerned period but numerical adequacy of observations that is required to test whether PPP deviations are mean-reverting or not. So, they use annual exchange rates of 150 countries covering 45 years since 1973 when exchange rate regime is flexible. They find that PPP deviations erode at rates between 12 percent and 15 percent, that is, half-life is four years. So, their estimated half-life of PPP deviations lay between those of Diebold et al. (1991) and Lothian and Taylor (1996). Above all, the half-life of PPP deviations ranges between three and six years.

6. Empirical Estimation of Half-life of Petrol-Price Dispersion Across Australian Cities

6.1 Estimation Techniques of Half-life of Petrol-Price Dispersion

This empirical section applies the previously used ADF unit root test (Levin and Lin 1992; Maddla and Wu 1999 and Im-Pesaran-Shin 2003) to estimate half-life of the petrol-price convergence across major Australian cities. In addition, this section applies recently developed Phillips-Sul (2007) econometric convergence test on the same item to verify the previous findings.

Phillips and Sul (2007) propose an approach (termed 'log t' regression test) which accommodates heterogeneous agent behaviour and its evolution. One advantage of this method is that it does not impose any particular assumption concerning trend stationary or stochastic non-stationarity. It, therefore, provides a robust estimate of the stationarity property of the series. To follow Phillips and Sul (2007), the econometric convergence test assumes that the data generating process is $X_{it} = g_{it}+a_{it}$ where, g_{it} represents systematic components such as permanent common components and a_{it} embodies transitory components. Rearranging the above components, X_{it} can be written as: $X_{it} = \left(\frac{g_{it}+a_{it}}{u_t}\right) * u_t = \delta_{it}u_t$; Where δ_{it} is a time varying idiosyncratic elements and u_t is a single common component.

The relative transition parameter (h_{it}) which measures the loading coefficient relative to the panel average at time t is: $h_{it} = \frac{X_{it}}{\frac{1}{N}\sum_{i=1}^{N} X_{it}} = \frac{\delta_{it}}{\frac{1}{N}\sum_{i=1}^{N} \delta_{it}}$. This equation satisfies that the cross sectional mean of h_{it} is unity and the cross-sectional variance of h_{it} satisfies the following condition: $H_{it} = \frac{1}{N}\sum_{i=1}^{N}(h_{it}-1)^2 \rightarrow 0 \; if \; \lim_{t\rightarrow\infty} \delta_{it} = \delta, for \; all \; i.$

Phillips and Sul (2007) develop the regression t test for the null hypothesis of convergence i.e.
H0: $\delta_i = \delta$. Specifically, the hypothesis test can be implemented through the following 'log t' regression model:

$$\log\left(\frac{H_1}{H_t}\right) - 2\log(log(t)) = a + blog(t) + \varepsilon_t \quad \text{for t= rT, rT+1, rT+2, ……., T with r > 0.}$$

Phillips and Sul (2007) further showed that it implies a one sided t-test i.e. $t_b = \frac{\hat{b}-b}{s_b} \sim N(0,1)$.

6.2 Estimation of Price Convergence

The data used in this empirical section is a panel data set containing daily petrol prices of major seven cities (e.g., Sydney, Melbourne, Brisbane, Adelaide, Perth, Darwin, and Hobart) of Australia. The data set being published by Australian Institute of Petroleum covers the 2004-2020 period. The underlying reasons of using the petrol price are (i) petrol is purchased by almost all motorists; (ii) it is a highly tradable commodity having similar use everywhere; and (iii) it has little product differentiation. The price movements in Figure 3 illustrate that it has similar trends in all cities while the differences are spectacularly visible between some cities.

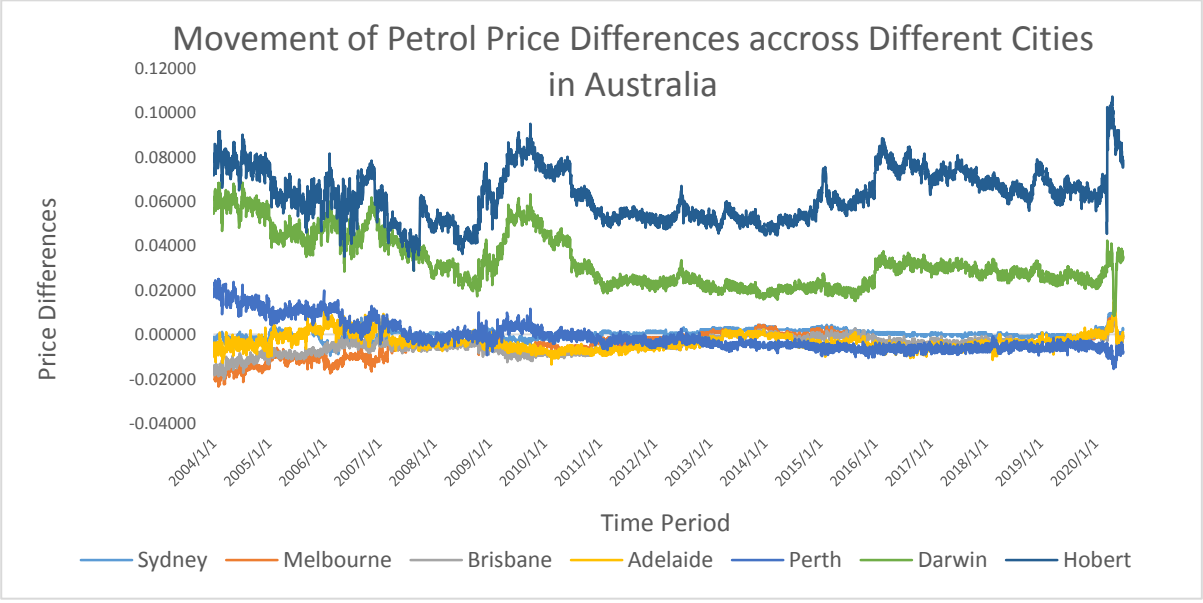

Figure 3. Movement of Petrol Price Differences across Different Cities in Australia during the study period

Having determined the optimum lag order of two by employing both Swartz Bayesian Information Criterion (SBC) and Akaike Information Criterion (AIC), the estimates of the equation (2) provide the beta coefficient as -0.0104 which implies that the half-life of petrol-price convergence is about two months or 66 days (Table 1). This convergence speed is quite similar to the same obtained for China by Fan and Wei (2006).

Table 1. Estimated Beta Coefficients and Speed of Convergence

Commodity	Lag	Coefficient	t-stat	Half-life	95% CI	R2	S.E.
Petrol price	2	-0.010399	-10.6*	66	-0.0123, -0.0085	0.22	0.001

Table 2. Phillips –Sul Econometric Convergence test result

Commodity	Coefficient	SE	t-stat
Petrol Price	-0.6979	0.2975	-2.3459*

Table 3. Panel Unit Root Test Using Maddala-Wu (MW), Im-Pesaran-Shin (IPS) and Levin-Lin-Chu (LLC) Test and Estimated Half-Lives

Commodity	Lag	MW test statistic	IPS test statistic	LLC			
				Test statistic	Coefficient	t--stat	Half-Life
Petrol price	2	704.87*	-10.09*	-6.114*	-.009327	-3.75*	75

Note: In all tables, * indicates significant at 1% level of significance.

The first lag coefficient of the LLC regression is also negative and statistically significant. This implies that price convergences occur, and their average half-life is about 2.5 months (Table 3). All these results are consistent with earlier review findings. Results also demonstrate that the convergence speed is slow even for a very highly tradable and unique commodity like the petrol.

7. Conclusion

An extensive review of the literature concerning violation of the LOP and estimation of the half-life of price convergence outlined above shows that researchers follow a systematic approach to this issue: (i) using econometric techniques they identify whether price convergence exists or not; (ii) if it exists, how fast price convergence takes place and thereafter identify what factors facilitates the speed of price convergence and how; and (iii) if it does not exist, how fast price divergence takes place and thereafter what factors contribute to the speed of price divergence and how. Researchers estimate the price convergence or divergence by following different measures and using different data sets depending on their objectives and the contexts (temporal and geographical). Regarding price convergence within a specific country they find that it depends on a wide range of factors: (i) the nature of goods (tradable versus non-tradable, perishable versus non-perishable); (ii) inputs used in the production of goods and hence productivity of inputs especially labour; (iii) the geographical distance among market places; (iv) the developmental level of transport and communication in concerned locations; (v) the frequency at which domestic prices are adjusted over time in response to demand and supply of products in the domestic market; (vi) the location-specific factors (e.g., consumer preferences); (vii) the extent to which and the frequency at which the volatility in the foreign exchange rate is transmitted to the domestic prices of imported goods and so on. The public policy regarding wage, price, tax, exchange rate and so on also influence the speed of and hence the half-live of the price convergence/dispersion.

With an increasing trend of globalization since 1980s excepting very recent years of economic nationalism being followed by a few large countries (e.g., the US's, India's and China's trade wars with the rest of the world), the volatility in the international foreign exchange market affects the speed of price convergence of an individual country's domestic market. The level of economic integration among countries also affects this speed of convergence. If a country is a member of an economic/monetary union, the level of integration among them influences price convergence among them.

The average half-life of products ranges from 2 months to 6 years depending on econometric techniques and data sets being used, products being included, and time horizon being considered. While the international foreign exchange market is very much well-integrated, the half-life of the PPP convergence between currencies of developed countries varies from 3 to 6 years depending on the currencies included. It seems very slow. Estimation of the half-life of goods and services in smaller developing countries is yet outside the research agenda of many researchers.

In order to verify speed of price convergence in Australia we estimate the half-life of petrol price convergence across major Australian cities and find that it varies from 66 to 75 days. It seems to be very slow in the context of well-developed transport and communication infrastructure across Australia. Future research may identify factors slowing down the speed of petrol price convergence in Australia.

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Notes

Note 1. The price of a same basket of goods and services across regions (within a country or among countries) expressed in terms of a common currency should be equal.

Note 2. The absolute LOP does not include the cost of arbitrage (any cost involved in the transfer of goods and services from buyers to sellers e.g., transportation costs, taxes, tariffs, and some hidden costs and so on), whereas the relative LOP does so. It suggests that in absence of arbitrage costs prices of a basket of goods and services should be

equal across regions (within a country or among countries within a trading block or the world) expressed in terms of a common currency should be equal.

Note 3. Identical technologies and product-mix and no possibility of factor intensity reversals.

Note 4. It is hard to find countries with identical technologies, identical product-mix, and no factor intensity reversals.

Note 5. Their volumes of factor endowments are similar. No tariff and non-tariff barriers are in place in the case of manufacturing goods. Their demand patterns are also similar.

Note 6. Prices of 271 goods drawn from major cities in seventy-one OECD countries and least-developed countries and prices of two hundred and forty-five goods drawn from thirteen major US cities).

Note 7. Gold standard pegged and adjustable pegged, fixed, and floating exchange rate regimes.