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A Triangular PPP Hypothesis

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Abstract: We propose a triangular PPP analytical framework, which is theoretically justified and empirically validated. The mechanisms and channels through which a seemingly mystery relationship emerges are deliberated and examined, which renders significant implications to international monetary economics, finance and business. The de facto peg of the RMB to the US dollar, together with trade activities and arrangements, causes a triangular PPP effect that the dollar euro exchange rate is not a function of the relative prices in the US and Euroland. Instead, it becomes a function of the relative prices in the PRC and Euroland. The results are supportive of triangular PPP in a three-economy world of the US, Euroland and PRC.

Key words: exchange rate; PPP; triangular PPP

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1. Introduction

Joseph Stiglitz roused the world economy once again by writing in *Vanity Fair* an article titled 'The Chinese Century' (*cf.* Stiglitz 2015), a fantasy momentously turned up afore the new millennium but soon evaporated, thanks to persistent US dominance. '2014 was the last year in which the United States could claim to be the world's largest economic power. China enters 2015 in the top position, where it will likely remain for a very long time, if not forever' (ibid). His assertion was thrashed out owing to purchasing power parity (PPP). So much so that PPP is debateable, at least for contributing to altering rankings of nations in GDP, another dubious economic indicator. PPP is relevant nonetheless – factual or perceived departures from PPP can actually distort the way in which international business is conducted. China comes to prominence, for the moment, due to her sheer size of population. China has exerted the growing phenomenal influence on the global economy in the last decade, which has been gradually acknowledged in the recent literature. Some China scholars, under the influence of China's policy makers and regulators, apply small open economy theories to a large, semi closed economy humbly. Regardless of domestic economic policy or exchange rate policy, China is affected by the world economy, the US primarily, but is not affecting the world economy, these China theorists maintain. Recent world stock markets turmoil in August 2015, instigated by the irregular alterations of the Shanghai Stock Exchange Composite Index, is the latest evidence squarely against these China theorists' approaches. 'China rattles markets with Yuan devaluation' (Bloomberg, 2015) is another. 'China's devaluation jolted global markets, with the currencies of South Korea, Australia and Singapore falling at least 1 percent …' (ibid). Hughes (2016) has provided an explainer as to why the RMB is rattling markets. As approved by the Executive Board of the IMF on November 30, 2015, effective October 1, 2016, the RMB has been included in the SDR basket as a fifth currency, with its weight in the basket being set at 10.92 percent, placed after 41.73 percent for the U.S. dollar and 30.93 percent for the euro while ahead of 8.33 percent for the Japanese yen and 8.09 percent for the sterling (IMF Communications

Department, 2016). This has effectively acknowledged that the RMB is now the world's third largest currency.

The present paper aims to address an issue, the phenomenon of which has been notified and reported by financial media clearly and widely for some time, the consequence of which has been communicated but the account of which has yet to be scrutinized by academia theoretically and empirically sooner rather than later. We are mindful of this issue, having been curious about the effect of the China variables – exchange rates and inflation – on the world economy. We move with time in conceptualizing triangular PPP against a backdrop of the perfunctory application of small open economy theory to a large semi closed economy – applying the right theory to the wrong place at the wrong time, which has in practice distorted world economic orders. At the same time, we have innovated theory in logical thinking at the time of accelerated globalization. We propose a triangular PPP analytical framework, which is theoretically justified and empirically validated. Our study is motivated by a dazzling foreign exchange market witnessed in recent years, arising to a certain extent suspiciously from the de facto peg of a large currency, i.e., the RMB, to the US dollar. A triangle, or a triangular circle of transactions, is formed in a triangular PPP analytical framework. It consists of two floating currencies, and a third currency pegged to one of the floating currencies. The triangular circle of transactions is bounded by non-arbitrage with the pegged currency. Non-arbitrage is upheld, whether PPP holds or not.

A triangular PPP effect comes into force when the exchange rate between the two floating currencies is not a function of the relative price levels in the two countries. That is, adopting consumer price indexes (CPIs) for price levels, the exchange rate between the two floating currencies is not a function of ratios between the CPIs of the two economies. Amazingly, it becomes a function of ratios between the CPIs of the pegging currency's economy and the economy of the floating currency that is not being pegged. This gives rise to triangular PPP. We hence raise two research questions: a) whether there exists a triangular PPP effect as described

above; b) what cause the triangular PPP effect to emerge? Testable hypotheses will be developed in Section 4 in answering these questions. We examine this triangular PPP effect empirically after presenting the analytical framework.

The rest of the paper progresses as follows. The next section provides a brief review of the pertinent emerging literature. The triangular PPP framework is outlined in Section 3. Then, Section 4 presents test specifications and Section 5 implements the triangular PPP analysis and reports the evidence. Finally, Section 6 summarizes this study.

2. A brief review of the literature

2.1. Recent developments in RMB studies

Remarking on pegs of a large currency to another large currency, Wang (2013) reasons 'A new issue has then emerged: the anchor, whether it is an anchor in a harbor or a large vessel, has itself been towed away, because the anchoring ship is simply too large. Consequently, the positions of all other boats have changed to varied degrees. Put it straightforwardly, the exchange rates between various pairs of currencies may be affected by such kind of anchoring'. The literature on pegs can be referred to Meissner and Oomes (2008) and Reinhart and Rogoff (2004). Meissner and Oomes (2008) review and summarize pegs and why countries peg their currencies to other currencies. Reinhart and Rogoff (2004) have examined extensively de facto peg regimes with natural classifications, detailing pegged floats and floating pegs. Many countries apply de facto pegs while claiming to have floated their currencies, and some other countries prefer de facto pegs to de jure pegs. Specific to the RMB case, we adopt loosely defined pegs here as suggested in Wang (2013): 'A peg is an action or motion by which the exchange rate moves consistently within a narrow band of fluctuations against a particular currency. The currency that pegs may appreciate (depreciate) all the way for a considerably long period. While the band remains narrow, the mean of the band changes and it changes consistently in one direction'.

McKinnon and Schnabl (2012) have observed the growing influence of China, proclaiming that China have gradually become an anchor for the greater East Asian economy, and then a fiscal stabilizer on the world stage since the new millennium. Specifically, Li and Zhang (2017) review the RMB internationalization process and present four interrelated aspects or steps of this process. They include the emergence of offshore RMB business, allowing Hong Kong residents to open RMB deposit accounts in local banks since 2004. It started to get momentum six years on in 2010 when a series of measures aimed at broadening the scope for RMB business had been introduced. The opening up of the capital account commenced long before the 2008 financial crisis and was made one of the top policy priorities in 2011. China has become increasingly engaged in international monetary cooperation. Between 2009 and 2015, the People's Bank of China (PBOC), the central bank, signed 32 currency swap agreements worth 3.1 trillion yuan. The long waited cross-border RMB trade settlement pilot scheme was introduced in July 2009. By the end of 2011, the accumulated total volume of trade settled in the RMB reached 2.08 trillion yuan. RMB trade settlements have been applied to all Chinese import and export enterprises as well as to all offshore trading partners since March 2012. These steps and measures have made China less detached from the world; they have allowed China to be more connected with the world, transmitting its influence. Xu and He (2016) have found that RMB cross-border settlements have exerted influence as well on the Chinese economy through various channels to and from the outside world. Simulating various economic and financial effects of China abroad, Tyers (2016) highlights China and global macroeconomic interdependence. It looks right for Ryan (2015) to suggest that the global economy is already close to operating with three exchange rate anchors: the US dollar, the euro and, increasingly, the RMB.

2.2. Review of the PPP literature

To conform to the weak form PPP and strong form PPP test specifications that will be presented in Section 4, we focus on tests of stationarity of real exchange rates and co-

movements between the nominal exchange rate and relative price levels. To begin with, we would like to point out the regime effect on the validity or deviations from PPP and adjustment mechanisms under different exchange rate regimes. The general consensus is that the results and findings for the validity of PPP are mixed. PPP holds for countries with flexible exchange rate regimes to a greater extent than for countries with fixed exchange rate regimes. Since most developed countries adopt flexible exchange rate regimes and many developing countries adopt fixed exchange rate regimes, it is inferred that PPP is more likely to hold between developed countries, and PPP is relatively less likely to hold between developing countries or between a developing country and a developed country. This is evident in Cashin and McDermott (2006), where the majority of countries experience finite deviations of real exchange rates from parity. The speed of parity reversion is found to be much faster for developed countries than for developing countries; and fairly plainly, to be considerably faster for countries with flexible nominal exchange rate regimes than countries with fixed nominal exchange rate regimes. Sarno and Valente (2006) summarize regime effects and mechanisms meticulously. They suggest that during fixed exchange rate regimes, relative prices adjust to restore long-run equilibrium when economies experience deviations from PPP, while exchange rates bear most of the burden of adjustment during flexible exchange rate regimes. Given the convention of small open economy thinking and empirical cases of small open economies in most studies, it is the price of the small open economy that adjusts to restore equilibrium from PPP deviations. In the present study, prices may not be responsive in fixed exchange rate regimes however, as the country adopting a fixed/pegged exchange rate regime is a large economy.

Early studies that resort to stationarity tests of real exchange rates have reported the rejection of PPP in the floating period. Examples can be found in Adler and Lehmann (1983), Darby (1983), Hakkio (1984), Meese and Rogoff (1988) and Baillie and McMahon (1989). Whereas newer studies carried out in the last decades either report mixed results or are in favor of PPP. The former includes Choi (2004), Nusair (2004), Narayan (2005) and Murray and Papell

(2005a, b). Scrutinizing the asymmetric adjustment process toward parity for a sample of nine Asian economies during the post-Bretton Woods floating exchange rate era, Holmes and Wang (2006) find that long-run purchasing power parity is most likely to hold with respect to positive deviations only in most cases in the sample. Using Eurostat data, Imbs *et al.* (2005) observe that the estimated persistence of real exchange rates falls dramatically when heterogeneity is taken into account. Its half-life may fall to as low as eleven months. Lean and Smyth (2007) also find evidence of PPP for two thirds in their sample of 15 Asian countries. Allowing for regime changes, Assaf (2008) claims to have found new evidence on the stationarity of bilateral real exchange rates. The study of Kanas (2006) alleges that there are periods over which the real exchange rate is stationary and PPP holds and periods over which the real exchange rate is non-stationary and PPP does not hold for most countries. Further it is found that the probability of the real exchange rate being stationary is less than 50% for most countries.

The implication of long-run PPP is generally interpreted as the co-movement of the nominal exchange rate and the relative price levels between the two countries. Increased international trade in goods and services has led to greater co-movement of prices internationally (Auer and Mehrotra, 2014). Adopting the Johansen procedure, MacDonald (1993) tests for a long-run relationship between exchange rates and relative prices for five bilateral US dollar exchange rates against the Canadian dollar, the French franc, the German mark, the Japanese yen and the British pound, using post Bretton Woods data from January 1974 to June 1990. He also tests for the proportionality of the exchange rate with respect to relative prices, which is equivalent to testing stationarity in real exchange rates. He reports that the co-movement thesis receives robust support from the data, whilst the proportionality thesis is given practically no support. Similar research is also followed by Cheung and Lai (1993), Cochrane and DeFina (1995), Kugler and Lenz (1993), Pippenger (1993), Jacobson and Nessen (2004), and Paya and Peel (2007), among others. More recently, Neely and Rapach (2011) decompose 64 national inflation rates into world, regional, and idiosyncratic components. The importance of the world

and regional components is found to differ substantially across countries and economic policy choices and development measures matters. Overall, their evidence is supportive of the co-movement between the exchange rate and the respective relative prices; but is less in favor of proportionality in the co-movement.

The above review demonstrates mixed results for PPP. Amongst the mixed results, PPP holds for countries with flexible exchange rate regimes to a greater extent than for countries with fixed exchange rate regimes. Likewise, PPP is more likely to hold between developed countries, and PPP is relatively less likely to hold between developing countries or between a developing country and a developed country. Absent obviously in the studies is the size or relative size of economies, which has been the norm for research on PPP, unquestioned as if self-evidently. Bring size into play, our analytical framework for a large currency with a semi-fixed/pegged exchange rate regime points to the prospect of the opposite mixed results, contributing to the literature.

3. The triangular PPP framework, mechanisms and implications

3.1. Gravity and momentum in PPP

We start with introducing global total purchasing power parity (GT PPP), which leads to triangular PPP to come to light. There are effects of gravity and momentum in GT PPP, where gravity is mostly relevant to absolute PPP while momentum plays a role in relative PPP. Let the euro be the denominator currency, then absolute PPP in logarithms and relative PPP are as follows:

$$Ln(e_{i,t}) = c_i + Ln(CPI_{i,t}) - Ln(CPI_{€,t}) \quad (1a)$$

$$\Delta e_{i,t} = \pi_{i,t} - \pi_{€,t} \quad (1b)$$

where $e_{i,t}$ is the exchange rate of the currency of the i^{th} economy, or simply the i^{th} currency, vis-à-vis the euro, quoted as the units of the i^{th} currency per euro; $CPI_{i,t}$ is the consumer price index

of the i^{th} economy at time t; $CPI_{€,t}$ is the consumer price index of the Euroland at time t; $\Delta e_{i,t}$ is the change in the exchange rate at time t; $\pi_{i,t}$ is the inflation rate in the i^{th} economy at time t; and $\pi_{€,t}$ is the inflation rate in the Euroland at time t. Now let us bring gravity and momentum into play, designating $f_i(G,M)$ as the gravity momentum function, where G is for gravity and M for momentum, for the i^{th} economy. Multiplying both sides of equation (1b) by the gravity momentum function leads to:

$$f_i(G,M) \cdot \Delta e_{i,t} = f_i(G,M) \cdot \pi_{i,t} - f_i(G,M) \cdot \pi_{€,t} \quad (2)$$

which is gravity momentum PPP between the i^{th} economy and the Euroland. Given n+1 economies in concern in a globe, GT PPP is derived through summations over n economies excluding the Euroland:

$$\sum_{i=1}^{n} f_i(G,M) \cdot \Delta e_{i,t} = \sum_{i=1}^{n} f_i(G,M) \cdot \pi_{i,t} - \sum_{i=1}^{n} f_i(G,M) \cdot \pi_{€,t} \quad (3)$$

or

$$\sum_{i=1}^{n} f_i(G,M) \cdot \Delta e_{i,t} = \sum_{i=1}^{n} f_i(G,M) \cdot \pi_{i,t} - f_{RoW}(G,M) \cdot \pi_{€,t} \quad (4)$$

where $f_{RoW}(G,M) = \sum_{i=1}^{n} f_i(G,M) = f_W(G,M) - f_€(G,M)$; $f_W(G,M)$ is the global or world total gravity and momentum, and $f_{RoW}(G,M)$ is the total gravity and momentum in the rest of world excluding the Euroland. Rearranging equation (4) leads to:

$$\pi_{€,t} = \sum_{i=1}^{n} \frac{f_i(G,M)}{f_{RoW}(G,M)} \pi_{i,t} - \sum_{i=1}^{n} \frac{f_i(G,M)}{f_{RoW}(G,M)} \Delta e_{i,t} \quad (5)$$

The above relationship tells that inflation in the Euroland would be influenced more by the inflation of the economies that possess greater gravity and momentum, and by the changes in the exchange rates between the euro and the currencies that possess greater gravity and momentum. The influence of small economies is negligible. Similarly, this notion applies to the US dollar, the RMB and other currencies.

{Table 1}

{Table 2}

Table 1 and Table 2 provide gravity and momentum data in terms of GDP, with the former being nominal GDP and the latter PPP GDP. Table 3a reports trade volumes between the US, EU (Euroland) and PRC from the US perspective; whereas Table 3b shows share and momentum figures. Table 4 presents trade volumes, shares and momentum figures between the US, EU (Euroland) and PRC from the EU perspective. It is observed in Table 1 that the sum of GDP of the US, Euroland and PRC has accounted over 50% of the world total GDP; and the sum of GDP of the US, EU and PRC has accounted 60% during the testing periods. The PRC has kept up a 2-digit growth rate in GDP in the testing period, exceeding the world average growth by a large margin; whereas GDP of the US, EU (Euroland) has been growing at slower paces usually below the world average. Table 2 indicates additionally the relative size of economies of the US, EU (Euroland) and PRC. The three columns under the heading of Relative Size/Ratio report these figures. The PRC economy overtook that of the Euroland since 2010, and that of the US since 2013 in terms of PPP GDP. The PRC's GDP growth or momentum has been even higher, and the difference with the US and EU (Euroland) has been even larger, than the figures in Table 1. Looking at the trade figures in Table 3b, US imports from the PRC and EU or Euroland combined (IMEUPRC, IM€PRC), i.e., exports to the US from the PRC and EU or Euroland combined, have accounted one third of total US imports from the world; e.g., the figure in 2009 was 37.07% and 32.69% respectively. US exports to these economies, however, constitute a smaller portion of the world total, between one fifth (EX€PRC) and a quarter (EXEUPRC). The US net import figures are more remarkable. US net imports from the PRC and EU (N EUPRC) or Euroland (N €PRC) have accounted more than half of its total net imports from the world from 2009 and risen to two thirds soon afterwards. Between the PRC and EU or Euroland, PRC net exports to the US (N PRC) have been much larger than the EU (N EU) or Euroland (N €z), and become more than twice as large since 2007. The extent to which PRC net exports to the US exceeding Euroland or EU net exports to the US (PRC-€z, PRC-EU), calculated as PRC net exports to the US minus Euroland or EU net exports to the US

being divided by the sum of PRC net exports and Euroland or EU net exports, has been over a third for the former and one fifth for the latter since 2005. The figures have kept growing, reaching 50% by 2008. US net imports from the PRC alone have exceeded 40% of the US total trade deficits since 2009. Table 4 presents EU and Euroland trade with the US and PRC, where EU figures are reported in place of incomplete Euroland data. Overall, the trade scenario between the US, PRC and EU or Euroland can be summarized as follows. The US has run a persistent trade deficit with the EU and Euroland throughout the period (NEU US, N€ US in Table 4a); the PRC has run a trade surplus with the EU and Euroland during the same period (NEU PRC, N€ PRC in Table 4a); The EU has run an overall trade surplus with the rest of the world from 2013 onwards (NEU W in Table 4a). EU trade with the US and PRC, both imports and exports, has accounted nearly 30 percent of its total trade with the world (IMPRCUS, EXPRCUS in Table 4b). It is observed that EU net imports from the PRC and US have accounted for over 50% of its net imports from the whole world between 2009 and 2012 (N PRCUS in Table 4b). As the US has run a trade deficit with the EU for the whole testing period (N US in Table 4b), EU net imports from the PRC alone are larger than its net imports from the PRC and US combined, fluctuating between 60% and 90% for most of the testing period (N PRC in Table 4b). The EU has run a trade surplus from 2013 onwards. A negative figure indicates the relative size of its trade deficit with the PRC and its overall trade surplus with the world; e.g., the figure was -269.83% in 2013. The extent to which PRC net exports to the EU or Euroland exceeding US net exports to the EU or Euroland (PRC-US, PRC-US(€) in Table 4b) has been several times as large.

{Table 3}

{Table 4}

The above data, figures and facts support a tri-polar case for the US, EU (Euroland) and PRC functions practically, given their massive gravities of dominance in the world and their enormous gravities and momentums to influence each other. The three economies are gigantic – their combined GDP has accounted 60% of the world total GDP during the testing periods. The three economies have the comparable size, with the PRC's PPP GDP overtaking that of the EU (Euroland) and US recently. Moreover, trade between the three economies is bulky, accounting for more than one third of the world total and for two thirds in terms of net exports (imports). The PRC had possessed the highest momentums in terms of GDP growth, doubling or more than doubling the growth in the US, EU or Euroland. The PRC momentums in trade and, in particular, net exports, are even more astronomical in trade dynamics. The PRC momentums in trade with the US are 50% over that exerted by the Euroland; the PRC momentums are several times higher than that of the US regarding trade with the EU or Euroland.

A tri-polar GT PPP for the US, PRC and Euroland is therefore stipulated, incorporating gravity and momentum factors, as follows:

$$\pi_{€,t} = \frac{f_{US}(G,M)}{f_{US+PRC}(G,M)}\pi_{US,t} + \frac{f_{PRC}(G,M)}{f_{US+PRC}(G,M)}\pi_{PRC,t}$$
$$-\frac{f_{US}(G,M)}{f_{US+PRC}(G,M)}\Delta e_{\$/€,t} - \frac{f_{PRC}(G,M)}{f_{US+PRC}(G,M)}\Delta e_{¥/€,t} \quad (6)$$

where $e_{¥/€,t}$ is the exchange rate between the RMB and the euro, defined as number of Yuan (RMB units) per euro, and $e_{\$/€,t}$ is defined as units of dollars per euro. The exchange rate change element can be rearranged, given the rather different relationships of the RMB with the US dollar and the euro, as follows:

$$-\frac{f_{US}(G,M)}{f_{US+PRC}(G,M)}\Delta e_{\$/€,t} - \frac{f_{PRC}(G,M)}{f_{US+PRC}(G,M)}\Delta e_{¥/€,t}$$
$$= -\frac{f_{US}(G,M)}{f_{US+PRC}(G,M)}\left(\Delta e_{¥/€,t} - \Delta e_{¥/\$,t}\right) - \frac{f_{PRC}(G,M)}{f_{US+PRC}(G,M)}\Delta e_{¥/€,t}$$
$$= -\Delta e_{¥/€,t} + \frac{f_{PRC}(G,M)}{f_{US+PRC}(G,M)}\Delta e_{¥/\$,t} \quad (6a)$$

where $e_{¥/\$,t}$ is defined as number of Yuan per dollar. The right hand side of the equation consists of a full $\Delta e_{¥/€,t}$ and a fraction of $\Delta e_{¥/\$,t}$ now. Given that the RMB is largely pegged to the US dollar, at least in the sense that the variation in the exchange rate of the RMB vis-à-vis the US dollar is much smaller and smoother than the variation in the exchange rate between the euro and the US dollar. So the exchange rate change element in the PPP relation is dominated by the change in the exchange rate between the RMB and the euro, which is as volatile and variable as the exchange rate between the US dollar and the euro, as the former is the product of the latter and the exchange rate between the RMB and the US dollar. Now let us turn to the inflation element in the PPP relation. Except the GDP gravity effect over the Euroland that is comparable between the US and PRC, the PRC has possessed the overwhelmingly greater trade gravity and momentum, as well as the GDP momentum, than the US to exert influence over the Euroland. We do not specify the form of the gravity momentum function, which can be the product of gravity and momentum, multiplying the individual effects. Accordingly, equation (6) can be approximated be become:

$$\pi_{€,t} \approx \pi_{PRC,t} - \Delta e_{¥/€,t} \tag{7a}$$

That is, PPP holds for the PRC and Euroland. The exchange rate change element can be rearranged in another way as follows:

$$-\frac{f_{US}(G,M)}{f_{US+PRC}(G,M)}\Delta e_{\$/€,t} - \frac{f_{PRC}(G,M)}{f_{US+PRC}(G,M)}\Delta e_{¥/€,t}$$

$$= -\frac{f_{US}(G,M)}{f_{US+PRC}(G,M)}\Delta e_{\$/€,t} - \frac{f_{PRC}(G,M)}{f_{US+PRC}(G,M)}\left(\Delta e_{\$/€,t} + \Delta e_{¥/\$,t}\right)$$

$$= -\Delta e_{\$/€,t} - \frac{f_{PRC}(G,M)}{f_{US+PRC}(G,M)}\Delta e_{¥/\$,t} \tag{6b}$$

The right hand side of the equation consists of a full $\Delta e_{\$/€,t}$ and a fraction of $\Delta e_{¥/\$,t}$ now. With the same analysis as in the above, the exchange rate change element in the PPP relation is dominated by the change in the exchange rate between the US dollar and the euro, and the PRC

has possessed the overwhelmingly greater gravity and momentum than the US to exert influence over the Euroland. Accordingly, equation (6) can be approximated be become:

$$\pi_{€,t} \approx \pi_{PRC,t} - \Delta e_{\$/€,t} \tag{7b}$$

That is, the dollar euro exchange rate becomes a function of the relative prices in the PRC and Euroland instead, rather than a function of the relative prices in the US and Euroland.

3.2. The analytical framework for triangular PPP

Given the analysis and analytical results in 3.1, let us now employ the RMB, the US dollar and the euro to make a triangle with the following bounding relationship:

$$e_{¥/€,t} = e_{\$/€,t} \cdot e_{¥/\$,t} \tag{8}$$

Taking a logarithmic operation for equation (8) yields:

$$Ln\left(e_{¥/€,t}\right) = Ln\left(e_{\$/€,t}\right) + Ln\left(e_{¥/\$,t}\right) \tag{9}$$

We now consider PPP for the three currencies. Since the RMB is pegged to the US dollar, the exchange rate between them is not expected to follow PPP. i.e., the following relationship is not expected to be upheld:

$$Ln\left(e_{¥/\$,t}\right) = c_1 + Ln\left(CPI_{¥,t}\right) - Ln\left(CPI_{\$,t}\right) \tag{10}$$

where $CPI_{¥,t}$ is the CPI of People's Republic of China (PRC) and $CPI_{\$,t}$ is the CPI of the US at time *t*, and c_1 is an intercept[1]. Whereas the dollar euro exchange rate can be expected to abide by PPP:

$$Ln\left(e_{\$/€,t}\right) = c_2 + Ln\left(CPI_{\$,t}\right) - Ln\left(CPI_{€,t}\right) \tag{11}$$

where $CPI_{€,t}$ is the CPI of Euroland at time *t*, and c_2 is an intercept. However, equation (11) is subject to empirical verification. The RMB euro exchange rate is "freely" floating, due to the fact that it is the product of the dollar euro exchange rate and the RMB dollar exchange rate, and the former is freely floating. So, it can be expected that:

[1] If we made all CPIs 100 in year 0, then c_1 is equal to $Ln\left(e_{¥/\$,0}\right)$.

$$Ln\left(e_{¥/€,t}\right) = c_3 + Ln\left(CPI_{¥,t}\right) - Ln\left(CPI_{€,t}\right) \quad (12)$$

where c_3 is an intercept. Equation (12) is also subject to empirical verification. If PPP holds empirically for the RMB euro exchange rate, then equation (12,5) is valid. According to equation (9) and equation (12):

$$Ln\left(e_{\$/€,t}\right) = c_4 + Ln\left(CPI_{¥,t}\right) - Ln\left(CPI_{€,t}\right) - Ln\left(e_{¥/\$,t}\right) \quad (13)$$

where c_4 is an intercept. Mathematically, bringing equation (10) back into equation (13) reproduces equation (11). However, this mathematical operation is valid if and only if the relationship in equation (10) is upheld. Given a pegged RMB that steadily appreciated against the US dollar, $Ln\left(e_{¥/\$,t}\right)$ is virtually a linear trend, with fluctuations much narrower than those associated with flexible exchange rates. So, equation (13) can be presented as:

$$Ln\left(e_{\$/€,t}\right) = c_4' + \delta t + Ln\left(CPI_{¥,t}\right) - Ln\left(CPI_{€,t}\right) + \nu_t \quad (14)$$

where δ is coefficient, and ν_t is a random variable with a zero mean, reflecting confined fluctuations in the RMB dollar exchange rate that is much narrower than those associated with flexible exchange rates. Given a steadily appreciating RMB vis-à-vis the US dollar, $E\{Ln\left(e_{¥/\$,t}\right)\} < 0$. So $\delta > 0$.

3.3. Mechanisms and channels of triangular PPP

Our test results indicate that equation (10) and equation (11) do not hold. But equation (12) does hold, revealed by equation (7a) through gravity and momentum analysis. That is, bilateral PPP does not hold for the pair of the RMB and the US dollar and the pair of the US dollar and the euro; whereas bilateral PPP holds for the pair of the RMB and the euro. Equation (13), the triangular PPP relationship, also holds, which is the consequence transited from the upheld and violated bilateral PPP relationships, demonstrated by the process leading to equation (7b). So, what are the mechanisms and channels, through which a seemingly mystery relationship emerges? Primarily, the gravity and momentum function play an overwhelmingly dominant role; however

gravity and momentum would not make triangular PPP happen alone without the de facto peg of the RMB to the US dollar. Export and import activities exert effects on exchange rates, prices and their movements, which are partly explained by the above trade gravity and momentum analysis. They are the main conventional channels for price and exchange rate adjustments, providing a mechanism for their interactions. Nonetheless, the choice of invoice currencies for export and import would produce different and specific effects. The peg of the RMB to the US dollar creates a special mechanism that drives the movement in the dollar euro exchange rate, as indicated by Wang (2013) and Wang and Zhang (2014). Facilitated by these mechanisms and channels of transmission, triangular PPP rises consequently. While the exchange rate pass-through being hampered between the US and Euroland due to the peg of the RMB to the dollar, the effect is fulfilled between the PRC and Euroland through the means of the euro that is floating against both the dollar and the RMB.

Let us consider the de facto peg of the RMB to the US dollar first, because it is the causes to several other effects. A peg is an action or motion by which the exchange rate moves consistently within a narrow band of fluctuations against a particular currency. In the case of the RMB, while the band remains narrow, the mean of the band changes and it changes consistently in one direction. That is, the RMB appreciates against the US dollar all the way for a considerably long period. It has been found that the steady appreciation of the RMB vis-à-vis the US dollar drives the euro, among others, to appreciate against the US dollar (Wang 2013). The peg and the way in which the RMB is pegged to the US dollar are decided by the PRC monetary authority, not determined by market forces. So the RMB dollar exchange rate is unlikely to be objective or fair. Given the influence of the RMB, the subjective RMB dollar exchange rate distorts the dollar euro exchange rate, in that the dollar euro exchange rate is under the influence of both market forces and the PRC monetary authority's policies. However, market forces are unrestricted to shape the RMB euro exchange rate. Somehow, the RMB euro exchange rate provides a channel to correct the distortions elsewhere and, may be fair in the end. Given that the RMB euro

exchange rate is the product of the RMB dollar exchange rate and the dollar euro exchange rate, an overvalued euro and an overvalued RMB against the US dollar offsets each other to a certain extent, making the RMB euro exchange rate fairer. The RMB euro exchange rate becomes just and 'objective' at one point of the 'certain extent', which seems to be attained in the real world.

Trade tends to exert effect on exchange rates, prices and their movements. Bear in mind that, although the RMB has recently become the fifth largest currency for international payments, its share accounts for a tiny 2% in the world. The US dollar and the euro continue to dominate international payments, with a share of over 40% and over 30% respectively (SWIFT 2016, 2018). Lai and Yu (2015) have shown these trade payment patterns. Exports and imports of Asian Pacific countries are predominantly invoiced in the US dollar, while the Japanese yen and the euro account for less than five percent each, and the rest of the currencies combined account for approximately fifteen percent. Whereas exports and imports of the Euroland are invoiced almost equally in the euro and the US dollar, with the euro share rising gradually; the British pound has accounted for approximately five percent and the rest of the currencies five percent. Thus PRC exports to the US are almost all invoiced in US dollars. The steady appreciation of the RMB vis-à-vis the US dollar makes PRC exporting firms' margins become thinner, but they strive not to increase dollar-denominated prices. Therefore, $CPI_{\$,t}$ is largely unaffected by changes in exchange rates. US exports to the PRC are almost all invoiced in US dollars, which produces a deflation effect on PRC import prices, given a steady appreciating RMB against the US dollar. $CPI_{¥,t}$ tends to rise slower to a certain extent, with the extent depending on the relative importance of the import price of US-imported goods in the overall $CPI_{¥,t}$. Euroland exports to the PRC are largely invoiced in the euro, which makes $CPI_{¥,t}$ be corresponding to PPP, though whether $e_{¥/€,t}$ is responsive to $CPI_{¥,t}$ or vice versa is subject to empirical examination. PRC exports to Euroland are largely invoiced in US dollars, which produces a deflation effect on Euroland's import prices, given the RMB effect on the dollar euro exchange rate. $CPI_{€,t}$ tends to

rise slower in this situation to a certain extent than in a situation without this effect, with the extent depending on the relative importance of the import price of PRC-imported goods in the overall $CPI_{€,t}$. US exports to Euroland are invoiced in US dollars and euros. The part of exports invoiced in US dollars produces a deflation effect on Euroland's import prices, given the RMB effect on the dollar euro exchange rate. $CPI_{€,t}$ tends to rise slower to a certain extent, with the extent depending on the relative importance of the import price of US-imported goods in the overall $CPI_{€,t}$. Euroland exports to the US are invoiced in US dollars and euros. There would produce some inflation effect on US import prices, but the effect is fairly week.

It can be summarized that $CPI_{€,t}$ is most responsive to such trade and settlement arrangements, followed by $CPI_{¥,t}$; while $CPI_{\$,t}$ is least responsive. Further, the steady appreciation of the RMB vis-à-vis the US dollar produces a deflation effect on $CPI_{€,t}$ and $CPI_{¥,t}$ and an inflation effect on $CPI_{\$,t}$, with the effect being the strongest on $CPI_{€,t}$ and the weakest on $CPI_{\$,t}$. The above analysis suggests that equation (10) is unlikely to be upheld. While $e_{¥/\$,t}$ moves in its own way controlled by the PRC monetary authority, $CPI_{\$,t}$ is not responsive to that movement. They are all detached from the bilateral PPP relationship. Equation (11) is also questionable, when $e_{\$/€,t}$ is driven by $e_{¥/\$,t}$ while $CPI_{\$,t}$ is not responsive. Contrary to all imaginations produced by small open economy thinking, equation (12) is most probable to hold. Both $CPI_{€,t}$ and $CPI_{¥,t}$ are responsive to trade and exchange rate movements, while $e_{¥/€,t}$ is unrestrictedly shaped by market forces.

Then, how do these adjustments and responses transit to equation (13)? The process starts with the particular peg of the RMB to the US dollar featured by the steady appreciation of the RMB vis-à-vis the US dollar, which drives the dollar euro exchange rate. Given that PRC exports to the US are invoiced in US dollars and the rest of trade is invoiced in US dollars and euros, $CPI_{\$,t}$ is unmoved by the movement in the dollar euro exchange rate, which is originated in the steady appreciation of the RMB vis-à-vis the US dollar. $CPI_{¥,t}$ is moved instead by the own

actions of the PRC monetary authority. While $CPI_{\$,t}$ and $e_{¥/\$,t}$ are detached from the bilateral PPP relationship of equation (10), $Ln(CPI_{¥,t}) - Ln(e_{¥/\$,t})$ becomes a "theoretical" US CPI in logarithm, $Ln(\widehat{CPI_{\$,t}})$. Equation (13) comes into existence when this theoretical US CPI replaces the actual US CPI in equation (11), fulfilling the transit to equation (13).

3.4. Discussions and implications

With $e_{¥/\$,t}$ in equation (13) being not determined by equation (10), the US price level is out of the equation for dollar euro exchange rate determination. This is reinforced by equation (14) where $Ln(e_{¥/\$,t})$ is represented more distinctly by $\delta t + \nu_t$. Moreover, equation (14) indicates that the euro would steadily appreciate vis-à-vis the US dollar at a time the general economic environment does not change. One of the unchanged general economic environment cases is that the relative price levels remain the same in equation (13) or equation (14). This is disquieting. It was exactly what had happened before the financial crisis. The culprit was δt, or the steady appreciation of the RMB against the US dollar, which is made obvious by the relationship in equation (14).

The above relationship, arising from the de facto peg of the RMB to the US dollar, crucially justifies why and how the dollar euro exchange rate can be a function of the price level in the PRC, or the relative prices in the PRC and Euroland. While the US price level is out of the equation, there is a role for the PRC price level in the equation. The peg of a large currency RMB to the US dollar effectively creates a union of currencies in which the RMB constitutes a large share. This gives rise to the role of PRC fundamentals in influencing the relative value of the US dollar vis-à-vis other currencies on the one hand; it distorts the exchange rates of the US dollar vis-à-vis other currencies on the other hand. The validity of either equation (13) (equation (14)) or equation (11) is then subject to empirical examination, depending on the extent of influence and distortion exerted by the peg of the RMB to the US dollar.

A joint examination of equation (11) and equation (13) provides us with a means to assessing the RMB effect. Assume a world consisting of three economies only: the US, Euroland and PRC. Under such circumstances, equation (11) and equation (13) would be validated or invalidated by the economic variables in these three economies only. If the RMB were a small currency, equation (13) would have been invalid. The assumptions on small open economics are that they are influenced by the world but they do not influence the world. Thus, the inflation in the PRC would have no impact on the dollar euro exchange rate. A valid equation (13), which invalidates equation (11) in the meantime, indicates a fully exerted RMB effect. Equation (11) should have held in a perfect world of these three economies only, if and when under no influence of PRC economic variables. A more valid equation (13) and less valid equation (11) indicate a stronger RMB effect, and vice versa.

The validity of equation (13) depends on the validity of equation (12), i.e., PPP holds for the pegging currency and the floating currency that is not being pegged: the RMB and the euro. Under such circumstances, the exchange rate between the two floating currencies is not the inflation differentials between themselves but the inflation differentials involving the third currency in a triangular circle. Triangular PPP holds for the two floating currencies under this circumstance, and the exchange rate between them becomes a function of inflation differentials between the pegging currency's economy and the economy of the floating currency that is not being pegged. As equation (14) is a simplified representation of equation (13), we call it simple triangular PPP, and then call equation (13) standard triangular PPP.

4. Test specifications

Bilateral PPP and triangular PPP are tested for the weak and strong form. Weak form tests are to examine whether the variables in equation (11), equation (12) and equation (13) are cointegrated respectively. In this regard, the validity of equation (13) depends on the validity of equation (12) to a lesser degree, which will be demonstrated in the following analysis of specifications.

For a weak form of PPP for the dollar euro exchange rate, it is to test whether a linear combination of $Ln(e_{\$/€,t})$, $Ln(CPI_{\$,t})$ and $Ln(CPI_{€,t})$ is stationary or not. It is expressed as follows:

$$Ln(e_{\$/€,t}) + \alpha_1 Ln(CPI_{\$,t}) + \beta_1 Ln(CPI_{€,t}) = \theta_{\$€,t} \quad (11')$$

where α_1 and β_1 are coefficients, and $\theta_{\$€,t}$ is the resultant combination. Weak form PPP holds for the dollar euro exchange rate if a linear combination of these three variables, or $\theta_{\$€,t}$, is stationary. Similarly for the RMB euro exchange rate, it is to test whether the following combination, or $\theta_{¥€,t}$, is stationary for the validity of weak form PPP:

$$Ln(e_{¥/€,t}) + \alpha_2 Ln(CPI_{¥,t}) + \beta_2 Ln(CPI_{€,t}) = \theta_{¥€,t} \quad (12')$$

where α_2 and β_2 are coefficients. Weak form triangular PPP holds for the dollar euro exchange if the following linear combination, or $\theta_{¥€\$,t}$, is stationary:

$$Ln(e_{\$/€,t}) + \alpha_3 Ln(CPI_{¥,t}) + \beta_3 Ln(CPI_{€,t}) + \gamma_3 Ln(e_{¥/\$,t}) = \theta_{¥€\$,t} \quad (13')$$

where α_3, β_3 and γ_3 are coefficients. Similar to the derivation of equation (14,7) from equation (13,6) and for cointegration tests, $Ln(e_{¥/\$,t})$ may be taken out from equation (13',6'), allowing a linear deterministic trend in test specifications:

$$Ln(e_{\$/€,t}) + \alpha_3' Ln(CPI_{¥,t}) + \beta_3' Ln(CPI_{€,t}) = \theta_{¥€\$,t}' \quad (14')$$

Strong form tests impose proportionate restrictions on the variables in the above three equations: $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_3' = -1$, $\beta_1 = \beta_2 = \beta_3 = \beta_3' = 1$, $\gamma_3 = 1$. So strong form tests assess whether the following residuals are stationary:

$$Ln(e_{\$/€,t}) - Ln(CPI_{\$,t}) + Ln(CPI_{€,t}) = c_2 + \varepsilon_{\$€,t} \quad (11'')$$

$$Ln(e_{¥/€,t}) - Ln(CPI_{¥,t}) + Ln(CPI_{€,t}) = c_3 + \varepsilon_{¥€,t} \quad (12'')$$

$$Ln(e_{\$/€,t}) - Ln(CPI_{¥,t}) + Ln(CPI_{€,t}) + Ln(e_{¥/\$,t}) = c_4 + \varepsilon_{¥€\$,t} \quad (13'')$$

$$Ln(e_{\$/€,t}) - Ln(CPI_{¥,t}) + Ln(CPI_{€,t}) = c_4' + \varepsilon_{¥€\$,t}' \quad (14'')$$

Given equation (9), equation (13") is exactly the same as equation (12"), so $\varepsilon_{¥€\$,t} \equiv \varepsilon_{¥€,t}$ and $c_4 = c_3$. This is exactly what has been said earlier in the previous section that the validity of equation (13) depends on the validity of equation (12), which refers to strong form PPP. However, when weak form PPP is introduced, varied results are allowed empirically for equation (12') and equation (13').

According to the analysis in sub-section 3.3, triangular PPP is brought about by several causal relationships. Therefore, these causal relationships should be tested as the root causes to triangular PPP. The following hypotheses summarize these causal relationships.

H_1: $e_{¥/\$,t}$ causes $e_{\$/€,t}$

H_2: $e_{\$/€,t}$ causes $CPI_{¥,t}$

H_3: $e_{\$/€,t}$ causes $CPI_{\$,t}$

H_4: $e_{¥/€,t}$ causes $CPI_{¥,t}$

H_5: $CPI_{¥,t}$ causes $e_{¥/€,t}$

It is expected that the null of H_1 and H_2 be accepted, the null of H_3 be rejected, and the null of at least one of H_4 and H_5 be accepted when triangular PPP comes into existence.

5. Evidence

Our data sets of exchange rates and CPIs start from July 2005, when the People's Bank of China announced/ adopted managed floating, and stop by June 2013. The data sets are at the monthly frequency, the highest frequency for inflation data. There are two major and authoritative souses of inflation statistics for PRC. One is National Bureau of Statistics of China (NBSC) and the other Organization for Economic Co-operation and Development (OECD). The inflation rate produced by NBSC is lower, sometimes considerably lower than that produced by OECD. It is difficult for us to take sides. So, we make three measures, or modified indexes for PRC inflation. The first is an average of the two indexes by NBSC and OECD. The second is the index by

NBSC alone. The third takes the improvement in PRC's economic statistics compilation into consideration. The scale of fallacy or erroneousness of statistical data has been reduced gradually, and the accuracy in statistical data has been raised too, with time going by. Thus, OECD's index is adopted for the period before the financial crisis, and then NBSC's index is employed for the post crisis period.

The three pairs of exchange rates and the corresponding CPI ratios are plotted in Figure 1, adopting the first measure for PRC inflation. The left side vertical axis is for exchange rates, and the right side vertical axis is for CPI ratio, being expressed in logarithmic forms. The top panel exhibits the RMB euro exchange rate and the CPI ratio between PRC and Euroland; the middle panel is for the dollar euro exchange rate and the CPI ratio between the US and Euroland; and the bottom panel demonstrates triangular PPP for the dollar euro exchange rate[2]. Figure 2 and Figure 3 replicate these graphs, using the second measure and third measure for PRC inflation respectively. Clearly, PPP does not hold for the dollar euro exchange rate and price movements in the US and Euroland, observing the middle panel of Figure 1. While the US price level was steadily slightly higher than that in Euroland, the exchange rate fluctuated spectacularly. The euro appreciated to a much greater extent as could be warranted by inflation differentials prior to the financial crisis; and swung volatilely, keeping no pace with inflation movements in the whole post-crisis period.

{Figure 1}

{Figure 2}

{Figure 3}

[2] The position of the RMB dollar exchange rate is shifted, so the two exchange rates are displayed close to each other.

In contrast, there were synchronised co-movements between the RMB euro exchange rate and the CPI ratio between PRC and Euroland, indicated by the top panel of Figure 1, Figure 2 and Figure 3 with three different CPI measures for PRC. Figure 3 exhibits the best fit graph, adopting the third CPI measure. More interestingly, the dollar euro exchange rate seemed to track the CPI ratio between PRC and Euroland instead, being augmented by the RMB dollar exchange rate. The dollar euro exchange rate tracked the CPI ratio between PRC and Euroland particularly well in the bottom panel of Figure 3. Moreover, all of Figure 1, Figure 2 and Figure 3 show that the sum of the three curves almost makes a stable line, indicating stationarity and upholding triangular PPP. Changes in the dollar euro exchange rate can be well matched by the joint movements in the CPI ratio between PRC and Euroland and the RMB dollar exchange rate, except for the period between October 2008 and June 2010 when the RMB dollar exchange rate was fixed for nearly two years. These graphical observations demonstrate mixed results for PPP contrary to the existing literature. PPP does not hold for economies with flexible exchange rate regimes, but seems to hold for a country with pegged exchange rate regimes, albeit in relation to an economy whose currency is not being pegged. The observations point to triangular PPP for the dollar euro exchange rate.

{Table 5}

{Table 6}

Our statistical estimation results also advocate triangular PPP in a three-economy world of the US, PRC and Euroland. A weak form of PPP for the RMB euro exchange rate is confirmed by the results in Table 5, indicated by one cointegration vector. Moreover, both standard triangular PPP and simple triangular PPP in their weak form are confirmed by the results in Table 5, given the established cointegration relationships. The results are consistent with all three CPI measures. These results are reinforced by unit root tests. Both ADF and PP tests reject the

null of a unit root with all three CPI measures for strong form PPP for the RMB euro exchange rate and strong form standard triangular PPP for the dollar euro exchange rate, as indicated by the results in Table 6. The confirmation of strong form simple triangular PPP is marginal nonetheless. The null of a unit root is rejected for two CPI measures, measure 1 and measure 3; and the rejection is at a low 10% significance level. Overall, a strong form of PPP for the RMB euro exchange rate and a strong form of triangular PPP for the dollar euro exchange rate are further established. There is no cointegration relationship between the dollar euro exchange rate and CPIs of the US and Euroland. The Johansen test results are peculiar, given three cointegration vectors, indicating the variables are "stationary" themselves. Moreover, both ADF and PP tests fail to reject a unit root, as reported in Table 6. Thus, PPP does not hold for the dollar euro exchange rate and the price levels in the US and Euroland in both strong and weak forms.

Next, causality relationships as postulated in H_1 to H_5 are tested, with the test results being reported in Table 7 and Table 8. The former is for long-run causality and the latter for short-term causality. H_1, changes in the RMB dollar exchange rate cause the dollar euro exchange rate to change, is accepted for long-run causality but not for short-term causality. The coefficient of the error correction term (ecm_{t-1}) is significant in the $\Delta e_{\$/€,t}$ equation at the 1% level and it is insignificant in the $\Delta e_{¥/\$,t}$ equation, as reported in Table 7. However, that $e_{¥/\$,t}$ is exogenous to $e_{\$/€,t}$ can't be rejected, inspecting the results in Table 8. That is, changes in the RMB dollar exchange rate cause the dollar euro exchange rate to change in the long-run, but they do not cause the dollar euro exchange rate to change in the short-term. Following the last financial crisis and between October 2008 and the first half of June 2010, the People's Bank of China suspended the exchange rate reform, i.e., the RMB was completely fixed to the US dollar, rather than pegged to the US dollar with narrow fluctuations, in this period. Wang and Zhang (2014) also document no short-tern causality from the RMB dollar exchange rate to the dollar euro

exchange rate including this period; nonetheless, they find short-term causality when this period is excluded. Long-run causality exits regardless of inclusion of this period.

{Table 7}

{Table 8}

Regarding H_2, the dollar euro exchange rate causes price movements in the PRC, the null is accepted for long-run causality with all three measures for the PRC's CPI, and is accepted for short-term causality with measure 1 and measure 2. The coefficient of ecm_{t-1} is highly significant at the 1% level in the $\Delta CPI_{¥,t}$ equation with all three measures and that that $e_{\$/€,t}$ is exogenous to $CPI_{¥,t}$ is rejected with measure 1 and measure 2. H_3, changes in the dollar euro exchange rate cause US prices to change, is rejected as expected. The coefficient of ecm_{t-1} is insignificant in the $\Delta CPI_{\$,t}$ equation in Table 7, and that $e_{\$/€,t}$ is exogenous to $CPI_{\$,t}$ is accepted in Table 8. These confirm our conjecture that $CPI_{\$,t}$ is unmoved by the movement in the dollar euro exchange rate. Both H_4 and H_5 are accepted. However, the influence of the RMB euro exchange rate on the PRC's CPI is much stronger than that of the PRC's CPI on the RMB euro exchange rate. H_4, changes in the RMB euro exchange rate move $CPI_{¥,t}$ is accepted for long-run causality at the 1% significance level; while H_5, developments in $CPI_{¥,t}$ cause the RMB euro exchange rate to change is rejected for long-run causality. With regard to short-term causality, that $e_{¥/€,t}$ is exogenous to $CPI_{¥,t}$ is rejected with two out of the three CPI measures, measure 1 and measure 2; similarly, that $CPI_{¥,t}$ is exogenous to $e_{¥/€,t}$ is also rejected with two out of the three CPI measures, measure 1 and measure 3. Given these empirical results, the causality between $e_{¥/€,t}$ and $CPI_{¥,t}$ is asymmetric, with the causality from the former to the latter being dominant.

Overall, our hypothesis test results confirm the postulated mechanisms and channels through which a triangular PPP relationship emerges. The root causes are the peg of the RMB to the US dollar, trade arrangements and invoice currency choices, which exert effects on exchange rates and prices and their movements and cause them to move in the way they have moved.

6. Summary

Motivated by a dazzling foreign exchange market in recent years, a triangular PPP hypothesis has been proposed in this paper. It is a response to addressing an emerging issue arising from the peg of the RMB to the US dollar. This emerging issue and the object in our study are in stark contrast to the issues and objects predominantly examined in the existing literature. Therefore, we depart from the traditional, standard models of exchange rate determination that can only work for small economies. With these models, the economy that adopts pegged exchange rate regimes plays no roles beyond its national borders, to which our thinking and analysis differ.

A triangular PPP analytical framework has been put forward in this paper thereby. The mechanisms and channels through which triangular PPP emerges have been deliberated. The joint effects of the peg of the RMB to the US dollar, trade activities and the choice of currencies with which exports and imports are invoiced have been evaluated, giving rise to a triangular PPP relationship. Empirically, a triangular PPP effect has been confirmed to exist that the dollar euro exchange rate becomes a function of CPI ratios between PRC and Euroland. Our results demonstrate mixed results for PPP as in the existing literature, but they are contrary to the general consensus in the literature that PPP holds for countries with flexible exchange rate regimes to a greater extent than for countries with fixed exchange rate regimes. In our cases, PPP does not hold for economies with flexible exchange rate regimes, but seems to hold for a country with pegged exchange rate regimes in relation to an economy whose currency is not being pegged.

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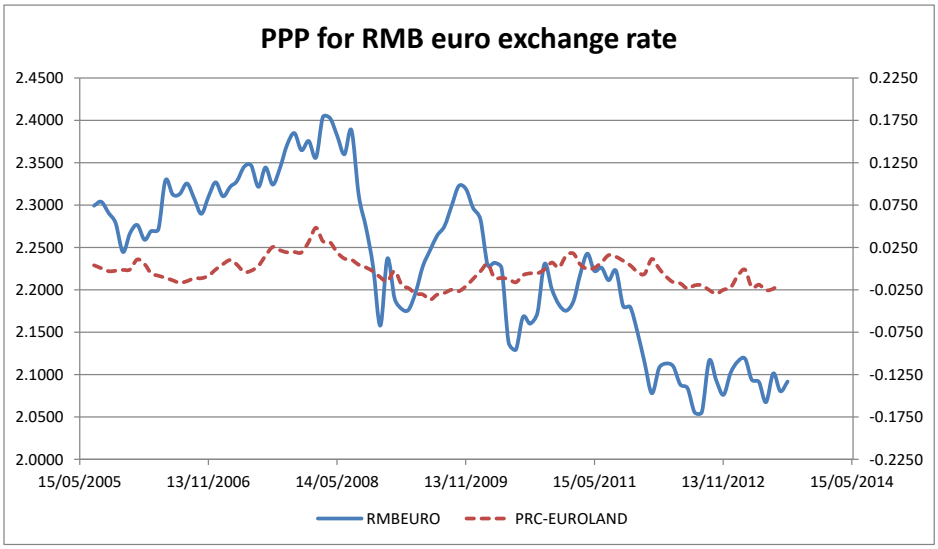
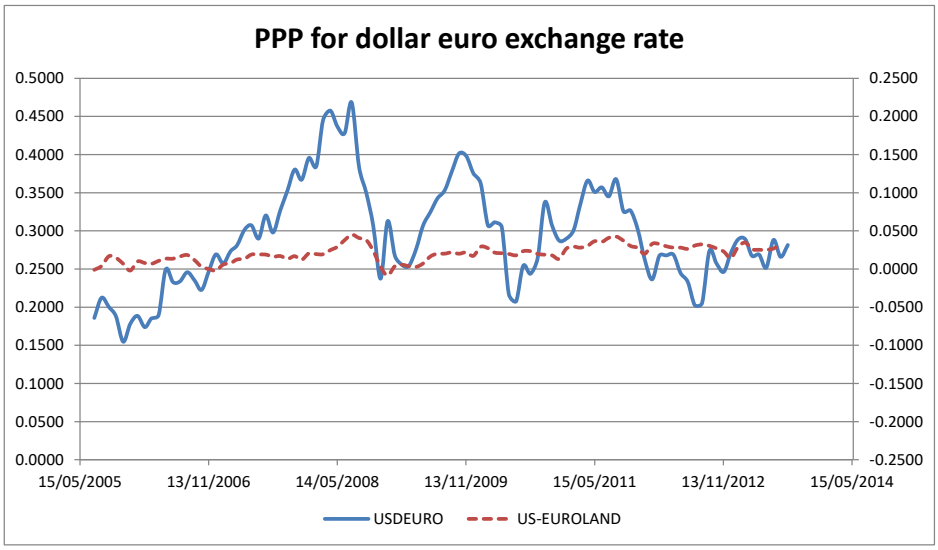




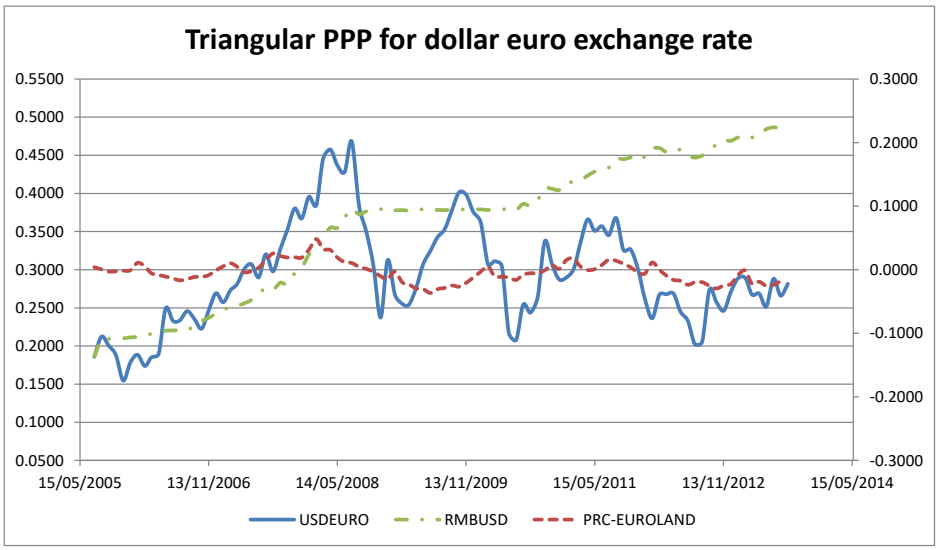
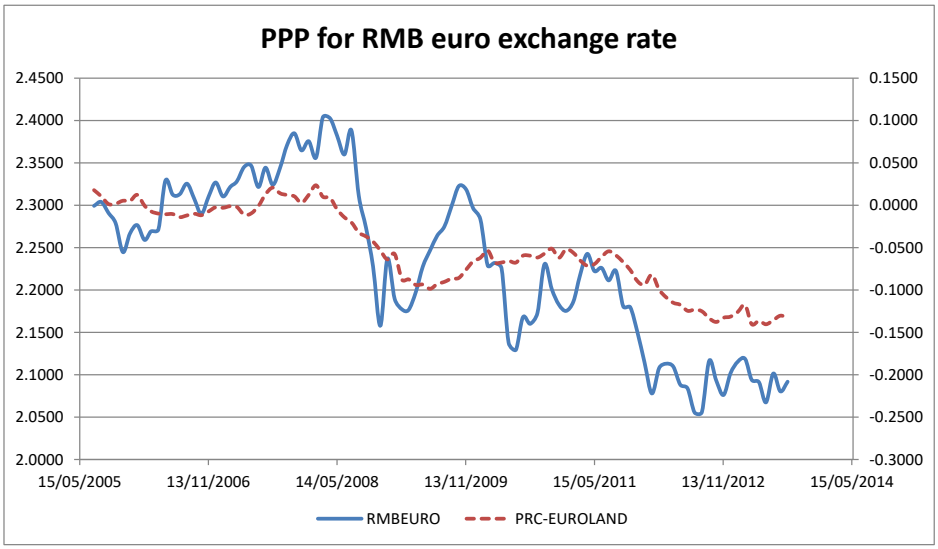


Figure 1. PPP and triangular PPP for the US, PRC and Euroland (with PRCCPI(1))



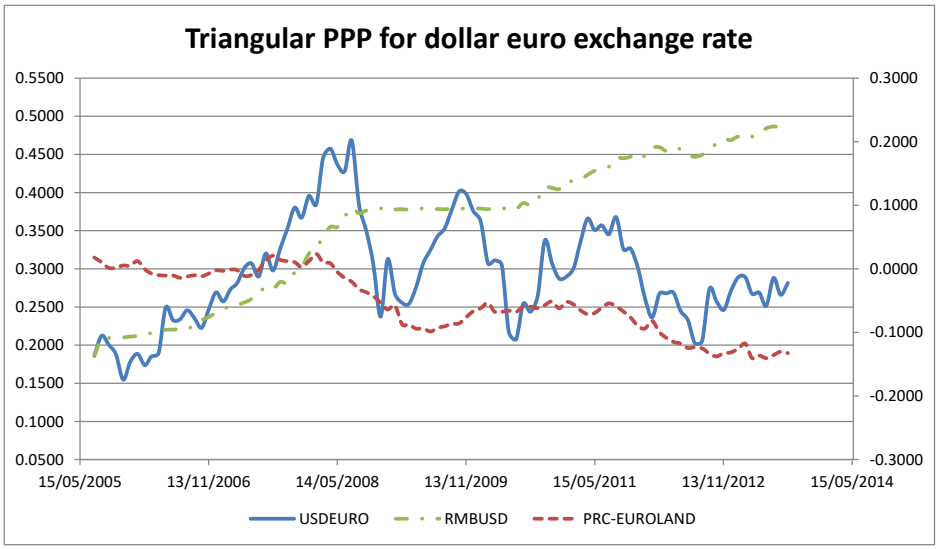
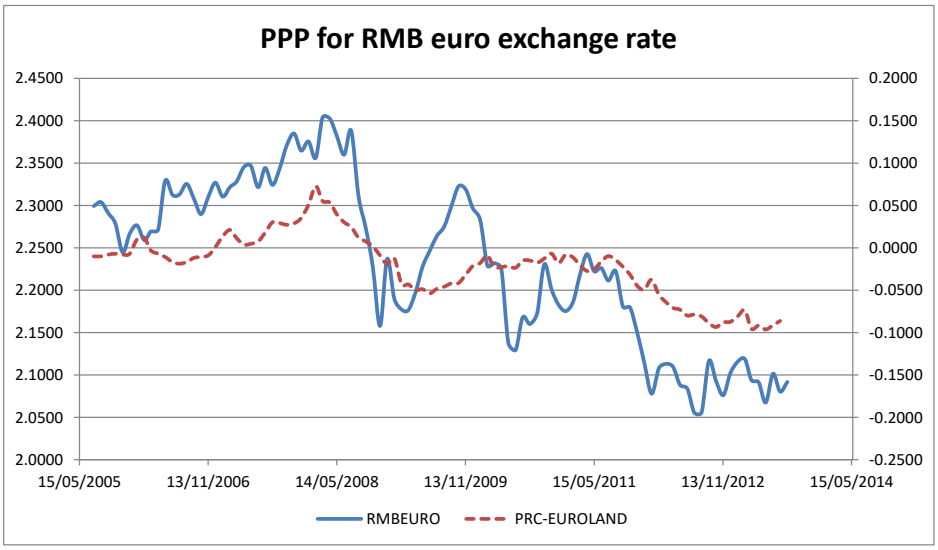


Figure 2. PPP and triangular PPP for the US, PRC and Euroland (with PRCCPI(2))



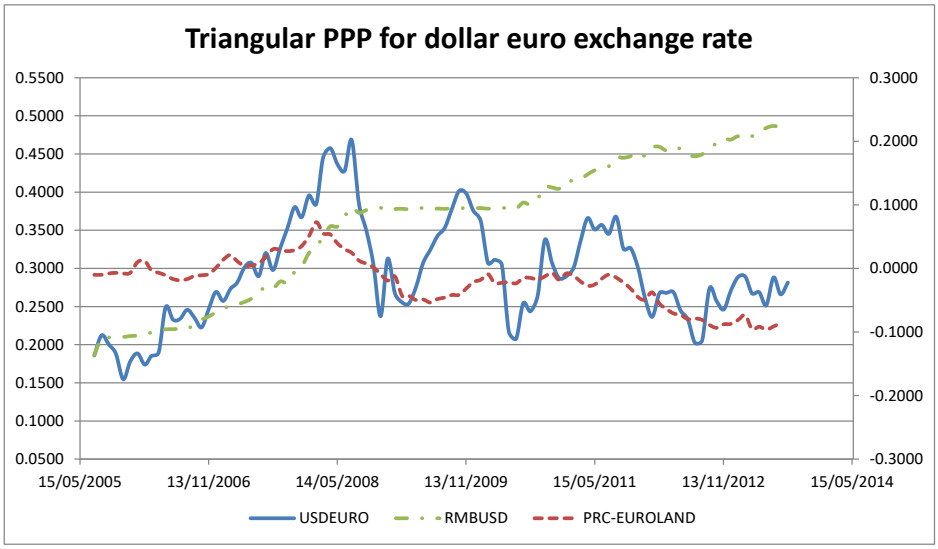


Figure 3. PPP and triangular PPP for the US, PRC and Euroland (with PRCCPI(3))

Table 1. GDP (nominal, current prices): volume, share and momentum

	GDP/Size/Gravity (Billions of US dollars)					Relative Size/Weight		GDP Growth/Momentum						
								PRC		euroland				
	PRC	euroland	EU	US	World	US€PRC / World	USEUPRC / World	in $	in ¥	in $	in €	EU	US	World
2000	1214.91	6498.35	8913.88	10284.75	33823.08	53.21%	60.35%							
2001	1344.10	6589.05	8997.19	10621.83	33579.21	55.26%	62.43%	10.63%	10.61%	1.40%	4.61%	0.93%	3.28%	-0.72%
2002	1477.48	7188.17	9828.53	10977.53	34711.51	56.59%	64.20%	9.92%	9.93%	9.09%	3.46%	9.24%	3.35%	3.37%
2003	1671.07	8854.69	11952.12	11510.68	38985.49	56.52%	64.47%	13.10%	13.10%	23.18%	2.88%	21.61%	4.86%	12.31%
2004	1966.22	10151.36	13794.87	12274.93	43887.80	55.58%	63.88%	17.66%	17.66%	14.64%	4.27%	15.42%	6.64%	12.57%
2005	2308.79	10539.69	14432.27	13093.70	47539.23	54.57%	62.76%	17.42%	16.25%	3.83%	3.62%	4.62%	6.67%	8.32%
2006	2774.31	11180.86	15387.74	13855.90	51465.81	54.04%	62.21%	20.16%	16.92%	6.08%	5.25%	6.62%	5.82%	8.26%
2007	3571.45	12885.94	17791.05	14477.63	58059.69	53.28%	61.73%	28.73%	22.83%	15.25%	5.58%	15.62%	4.49%	12.81%
2008	4604.29	14178.83	19202.99	14718.58	63649.97	52.63%	60.53%	28.92%	17.75%	10.03%	2.48%	7.94%	1.66%	9.63%
2009	5121.68	12938.58	17122.47	14418.73	60280.21	53.88%	60.82%	11.24%	9.36%	-8.75%	-3.58%	-10.83%	-2.04%	-5.29%
2010	6066.35	12666.92	17003.82	14964.40	65906.43	51.13%	57.71%	18.44%	17.38%	-2.10%	2.76%	-0.69%	3.78%	9.33%
2011	7522.10	13633.49	18354.51	15517.93	73119.33	50.16%	56.61%	24.00%	18.34%	7.63%	2.64%	7.94%	3.70%	10.94%
2012	8570.35	12644.65	17288.18	16155.25	74488.51	50.17%	56.40%	13.94%	11.31%	-7.25%	0.38%	-5.81%	4.11%	1.87%
2013	9635.03	13192.28	18009.20	16691.50	76551.27	51.62%	57.92%	12.42%	10.35%	4.33%	0.99%	4.17%	3.32%	2.77%
2014	10534.53	13492.68	18626.35	17427.60	78594.42	52.75%	59.28%	9.34%	8.41%	2.28%	2.24%	3.43%	4.41%	2.67%
2015	11226.19	11649.08	16371.32	18120.70	74311.46	55.17%	61.52%	6.57%	8.02%	-13.66%	3.52%	-12.11%	3.98%	-5.45%
2016	11232.11	11922.52	16447.54	18624.45	75367.75	55.43%	61.44%	0.05%	6.75%	2.35%	2.60%	0.47%	2.78%	1.42%

Sources: IMF

Table 2. GDP (PPP): volume, share and momentum

	GDP/Size/Gravity (Billions of international dollars)					Relative Size/Weight		Relative Size/Ratio			GDP Growth/Momentum				
	PRC	euroland	EU	US	World	US€PRC / World	USEUPRC / World	PRC: euroland	PRC: EU	PRC: US	PRC	euroland	EU	US	World
2000	3698.62	8709.84	11756.03	10284.75	49614.63	45.74%	51.88%	0.42	0.31	0.36					
2001	4096.90	9108.52	12304.52	10621.83	51987.32	45.83%	51.98%	0.45	0.33	0.39	10.77%	4.58%	4.67%	3.28%	4.78%
2002	4538.33	9346.96	12672.40	10977.53	54314.84	45.78%	51.90%	0.49	0.36	0.41	10.77%	2.62%	2.99%	3.35%	4.48%
2003	5091.71	9608.93	13117.57	11510.68	57656.92	45.46%	51.55%	0.53	0.39	0.44	12.19%	2.80%	3.51%	4.86%	6.15%
2004	5760.13	10092.70	13834.69	12274.93	62361.09	45.10%	51.11%	0.57	0.42	0.47	13.13%	5.03%	5.47%	6.64%	8.16%
2005	6617.29	10603.82	14600.41	13093.70	67415.36	44.97%	50.90%	0.62	0.45	0.51	14.88%	5.06%	5.53%	6.67%	8.10%
2006	7686.84	11295.52	15584.54	13855.90	73207.08	44.86%	50.72%	0.68	0.49	0.55	16.16%	6.52%	6.74%	5.82%	8.59%
2007	9011.95	11957.60	16526.36	14477.63	79281.54	44.71%	50.47%	0.75	0.55	0.62	17.24%	5.86%	6.04%	4.49%	8.30%
2008	10070.85	12238.36	16952.41	14718.58	83179.47	44.52%	50.18%	0.82	0.59	0.68	11.75%	2.35%	2.58%	1.66%	4.92%
2009	11080.89	11766.90	16338.56	14418.73	83478.95	44.64%	50.12%	0.94	0.68	0.77	10.03%	-3.85%	-3.62%	-2.04%	0.36%
2010	12405.88	12150.68	16879.04	14964.40	88996.82	44.41%	49.72%	1.02	0.73	0.83	11.96%	3.26%	3.31%	3.78%	6.61%
2011	13864.86	12587.80	17518.02	15517.93	94486.49	44.42%	49.64%	1.10	0.79	0.89	11.76%	3.60%	3.79%	3.70%	6.17%
2012	15235.77	12708.72	17767.50	16155.25	99270.23	44.42%	49.52%	1.20	0.86	0.94	9.89%	0.96%	1.42%	4.11%	5.06%
2013	16689.40	12881.82	18101.58	16691.50	104153.07	44.42%	49.43%	1.30	0.92	1.00	9.54%	1.36%	1.88%	3.32%	4.92%
2014	18228.36	13253.78	18718.92	17393.10	109553.54	44.61%	49.60%	1.38	0.97	1.05	9.22%	2.89%	3.41%	4.20%	5.19%
2015	19695.74	13660.72	19343.56	18036.65	114136.58	45.03%	50.01%	1.44	1.02	1.09	8.05%	3.07%	3.34%	3.70%	4.18%
2016	21269.02	14073.23	19973.04	18561.93	119097.43	45.26%	50.21%	1.51	1.06	1.15	7.99%	3.02%	3.25%	2.91%	4.35%

Sources: IMF

Table 3a. US imports from and exports to EU, eurozone, PRC and world: import and export volume, net import volume

(Billions of US dollars)

	IM EU	EX EU	IM €z	EX €z	IM PRC	EX PRC	IM W	EX W	N EU	N €z	N PRC	N World
2000	226901	168181	166362	119016	100018	16185	1218023	781918	58720	47346	83833	436105
2001	226568	161931	168081	114328	102278	19182	1140998	729101	64637	53754	83096	411898
2002	232313	146621	174279	107552	125193	22128	1161366	693101	85692	66728	103065	468265
2003	253042	155170	190186	115368	152436	28368	1257121	724771	97872	74818	124068	532350
2004	281959	171230	213180	127985	196682	34428	1469705	814875	110729	85196	162254	654830
2005	309628	185166	232240	138811	243470	41192	1673454	901082	124462	93428	202278	772372
2006	330482	211887	250479	157079	287774	53673	1853938	1025967	118595	93401	234101	827971
2007	354409	244166	269730	180753	321443	62937	1956961	1148199	110243	88977	258506	808762
2008	367617	271810	280433	202390	337773	69733	2103641	1287442	95807	78042	268040	816199
2009	281801	220599	213507	163040	296374	69497	1559625	1056043	61202	50467	226877	503582
2010	319264	239591	243777	177302	364953	91911	1913857	1278495	79673	66474	273042	635362
2011	368464	269069	285934	196453	399371	104122	2207954	1482508	99395	89482	295250	725447
2012	381755	265373	295314	193310	425619	110517	2276267	1545821	116383	102004	315103	730446
2013	387510	262095	303229	197524	440430	121746	2267987	1578517	125415	105704	318684	689470
2014	420609	276274	329111	204665	468475	123657	2356356	1621874	144334	124446	344818	734482
2015	427537	271880	332087	199465	483189	115932	2248183	1503101	155657	132622	367257	745082
2016	416377	269617	325184	198109	462618	115602	2187805	1451011	146760	127075	347016	736794

Sources: US Census Bureau

Table 3b. US imports from and exports to EU, eurozone, PRC and world: import and export share, net import share,

	IMEUPRC	EXEUPRC	IM€PRC	EX€PRC	N EUPRC	N €PRC	N EU	N €z	N PRC	PRC-EU	PRC-€z
2000	26.84%	23.58%	21.87%	17.29%	32.69%	30.08%	13.46%	10.86%	19.22%	0.1762	0.2781
2001	28.82%	24.84%	23.70%	18.31%	35.87%	33.22%	15.69%	13.05%	20.17%	0.1249	0.2144
2002	30.78%	24.35%	25.79%	18.71%	40.31%	36.26%	18.30%	14.25%	22.01%	0.0920	0.2140
2003	32.25%	25.32%	27.25%	19.83%	41.69%	37.36%	18.38%	14.05%	23.31%	0.1180	0.2476
2004	32.57%	25.24%	27.89%	19.93%	41.69%	37.79%	16.91%	13.01%	24.78%	0.1887	0.3114
2005	33.05%	25.12%	28.43%	19.98%	42.30%	38.29%	16.11%	12.10%	26.19%	0.2382	0.3681
2006	33.35%	25.88%	29.03%	20.54%	42.60%	39.55%	14.32%	11.28%	28.27%	0.3275	0.4296
2007	34.54%	26.75%	30.21%	21.22%	45.59%	42.96%	13.63%	11.00%	31.96%	0.4021	0.4879
2008	33.53%	26.53%	29.39%	21.14%	44.58%	42.40%	11.74%	9.56%	32.84%	0.4734	0.5490
2009	37.07%	27.47%	32.69%	22.02%	57.21%	55.07%	12.15%	10.02%	45.05%	0.5751	0.6361
2010	35.75%	25.93%	31.81%	21.06%	55.51%	53.44%	12.54%	10.46%	42.97%	0.5482	0.6084
2011	34.78%	25.17%	31.04%	20.27%	54.40%	53.03%	13.70%	12.33%	40.70%	0.4963	0.5348
2012	35.47%	24.32%	31.67%	19.65%	59.07%	57.10%	15.93%	13.96%	43.14%	0.4605	0.5109
2013	36.51%	24.32%	32.79%	20.23%	64.41%	61.55%	18.19%	15.33%	46.22%	0.4352	0.5019
2014	37.73%	24.66%	33.85%	20.24%	66.60%	63.89%	19.65%	16.94%	46.95%	0.4099	0.4696
2015	40.51%	25.80%	36.26%	20.98%	70.18%	67.09%	20.89%	17.80%	49.29%	0.4047	0.4694
2016	40.18%	26.55%	36.01%	21.62%	67.02%	64.35%	19.92%	17.25%	47.10%	0.4056	0.4639

Sources: US Census Bureau

Table 4a. EU imports from and exports to PRC, US and world

(Billions of euros)

	IMEU PRC	EXEU PRC	IM€ PRC	EX€ PRC	IMEU US	EXEU US	IM€ US	EX€ US	IMEU W	EXEU W	NEU PRC	NEU US	N€ PRC	N€ US	NEU W
2003	106579	41477	76107	35184	158141	227427	111791	168855	934974	861923	65102	-69286	40923	-57063	73051
2004	129203	48382	94331	40836	159666	235669	114960	176022	1027392	945185	80821	-76002	53495	-61061	82207
2005	161008	51749	119613	43608	159174	250821	120591	186884	1183909	1049477	109259	-91647	76005	-66293	134432
2006	195816	63696	145885	54044	170658	267034	126466	201405	1368254	1152485	132121	-96376	91841	-74939	215768
2007	233863	71823	173864	60523	177414	259613	132218	196347	1450340	1234482	162040	-82199	113341	-64128	215858
2008	249102	78301	186378	65703	182780	248057	138051	188697	1585231	1309147	170802	-65277	120675	-50646	276084
2009	215274	82421	158855	69482	155251	203756	116958	153730	1235636	1093961	132853	-48506	89373	-36772	141675
2010	283931	113454	211199	95774	174893	243345	131255	183262	1531518	1354055	170477	-68452	115426	-52006	177463
2011	295055	136415	219341	115645	194233	264240	143181	201317	1729980	1554511	158641	-70007	103696	-58136	175469
2012	292122	144227	214684	120570	209304	293475	153976	224889	1798757	1684928	147895	-84171	94113	-70913	113829
2013	280151	148115	204547	121908	199249	289313	152848	222980	1687440	1736373	132036	-90064	82639	-70133	-48933
2014	302518	164623	218833	131958	209334	311547	156769	241611	1692830	1703458	137895	-102213	86875	-84842	-10628
2015	350846	170357	249517	131255	249240	371288	184150	282415	1730168	1789967	180489	-122048	118263	-98266	-59799
2016	344911	169686	244868	138746	250519	363456	183510	280504	1712713	1744239	175225	-112937	106122	-96994	-31525

Sources: European Commission EU trade position in world statistics

Table 4b. EU imports from and exports to PRC, US and world

	IMPRCUS	EXPRCUS	N PRCUS	N PRC	N US	PRC-US	PRC-US(€)
2003	28.31%	31.20%	-5.73%[a]	89.12%	-94.85%	-32.1215[b]	-6.0708[c]
2004	28.12%	30.05%	5.86%	98.31%	-92.45%	32.5457	-15.1404
2005	27.04%	28.83%	13.10%	81.27%	-68.17%	11.4074	14.6513
2006	26.78%	28.70%	16.57%	61.23%	-44.67%	6.3924	9.8676
2007	28.36%	26.85%	36.99%	75.07%	-38.08%	3.0591	3.6062
2008	27.24%	24.93%	38.22%	61.87%	-23.64%	2.2372	2.4464
2009	29.99%	26.16%	59.54%	93.77%	-34.24%	2.1501	2.3982
2010	29.96%	26.35%	57.49%	96.06%	-38.57%	2.3419	2.6401
2011	28.28%	25.77%	50.51%	90.41%	-39.90%	2.5797	3.5521
2012	27.88%	25.98%	55.98%	129.93%	-73.94%	3.6417	7.1132
2013	28.41%	25.19%	-85.77%	-269.83%	184.06%	5.2916	12.2152
2014	30.24%	27.95%	-335.74%	-1297.48%	961.75%	6.7291	84.4447
2015	34.68%	30.26%	-97.73%	-301.83%	204.10%	5.1767	10.8279
2016	34.77%	30.57%	-197.58%	-555.82%	358.24%	4.6263	22.2513

Sources: European Commission EU trade position in world statistics

a, b – US trade deficit with EU was larger than PRC trade surplus with EU; c – US trade deficit was larger than PRC trade surplus with euroland

Table 5. Johansen cointegration tests for weak form PPP and weak form triangular PPP

		λ_{max}	Prob.	Trace	Prob.
PPP for	r = 0:	29.2358	0.0046	47.7053	0.0014
$e_{¥/€,t}$ (measure 1)	r = 1:	11.9345	0.1898	18.4695	0.0866
PPP for	r = 0:	25.8963	0.0150	42.0176	0.0079
$e_{¥/€,t}$ (measure 2)	r = 1:	10.7776	0.2687	16.1213	0.1688
PPP for	r = 0:	26.5199	0.0121	45.3386	0.0029
$e_{¥/€,t}$ (measure 3)	r = 1:	12.6082	0.1534	18.8187	0.0780
Standard triangular PPP	r = 0:	41.8995	0.0006	73.6561	0.0004
for $e_{\$/€,t}$ (measure 1)	r = 1:	21.8847	0.0571	31.7566	0.1121
Standard triangular PPP	r = 0:	48.8672	0.0000	80.0020	0.0001
for $e_{\$/€,t}$ (measure 2)	r = 1:	21.9493	0.0559	31.1347	0.1284
Standard triangular PPP	r = 0:	44.3581	0.0002	73.5642	0.0004
for $e_{\$/€,t}$ (measure 3)	r = 1:	19.4645	0.1188	29.2061	0.1915
Simple triangular PPP	r = 0:	35.6594	0.0018	49.8127	0.0089
for $e_{\$/€,t}$ (measure 1)	r = 1:	7.4020	0.8715	14.1533	0.6450
Simple triangular PPP	r = 0:	28.2874	0.0232	44.3043	0.0360
for $e_{\$/€,t}$ (measure 2)	r = 1:	9.4917	0.6731	16.0169	0.4912
Simple triangular PPP	r = 0:	27.0079	0.0348	46.6642	0.0201
for $e_{\$/€,t}$ (measure 3)	r = 1:	12.6575	0.3564	19.6563	0.2438

Table 6. Tests for strong form PPP and strong form triangular PPP

	ADF	PP
$\varepsilon_{\$€,t}$	-2.4598	-2.4966
$\varepsilon_{¥€,t}$ or $\varepsilon_{¥€\$,t}$ (measure 1)	-3.9819**	-3.1401*
$\varepsilon_{¥€,t}$ or $\varepsilon_{¥€\$,t}$ (measure 2)	-3.1983*	-3.2386*
$\varepsilon_{¥€,t}$ or $\varepsilon_{¥€\$,t}$ (measure 3)	-4.8074***	-3.5644**
$\varepsilon'_{¥€\$,t}$ (measure 1)	-2.8063*	-2.8284*
$\varepsilon'_{¥€\$,t}$ (measure 2)	-2.4815	-2.4323
$\varepsilon'_{¥€\$,t}$ (measure 3)	-2.7423*	-2.6888*

* reject a unit root at the 10% level, ** at the 5% level, *** at the 1% level

Table 7. Error correction model results: long-run

		Coef of ecm_{t-1}	t - stat		Coef of ecm_{t-1}	t - stat
H_1	in $\Delta e_{\$/€,t}$ eq	-0.1991***	-3.5488	in $\Delta e_{¥/\$,t}$ eq	-0.0046	-0.5043
H_2(m1)	in $\Delta e_{\$/€,t}$ eq	-0.0830	-1.6284	in $\Delta CPI1_{¥,t}$ eq	-0.0203***	-2.6393
H_2(m2)	in $\Delta e_{\$/€,t}$ eq	-0.0095	-0.2706	in $\Delta CPI2_{¥,t}$ eq	-0.0143***	-3.3427
H_2(m3)	in $\Delta e_{\$/€,t}$ eq	-0.0044	-0.3903	in $\Delta CPI3_{¥,t}$ eq	-0.0073***	-3.4371
H_3	in $\Delta e_{\$/€,t}$ eq	-0.1427***	-2.5663	in $\Delta CPI_{\$,t}$ eq	-0.0007	-0.1241
H_4/H_5(m1)	in $\Delta e_{¥/€,t}$ eq	-0.0802	-1.3697	in $\Delta CPI1_{¥,t}$ eq	-0.0269***	-2.7818
H_4/H_5(m2)	in $\Delta e_{¥/€,t}$ eq	-0.0005	-0.0815	in $\Delta CPI2_{¥,t}$ eq	-0.0046***	-4.5609
H_4/H_5(m3)	in $\Delta e_{¥/€,t}$ eq	-0.0078	-0.6953	in $\Delta CPI3_{¥,t}$ eq	-0.0081***	-3.3762

* significant at the 10% level; ** significant at the 5% level; *** significant at the 1% level.

Table 8. Granger causality/block exogeneity Wald tests: short-term

		Chi-sq	d.f.	Prob.
H_1	$e_{\$/€,t}$ is exogenous to $e_{¥/\$,t}$	1.7302	4	0.7852
	$e_{¥/\$,t}$ is exogenous to $e_{\$/€,t}$	5.5494	4	0.2354
H_2(m1)	$e_{\$/€,t}$ is exogenous to $CPI1_{¥,t}$	21.2837	13	0.0675
	$CPI1_{¥,t}$ is exogenous to $e_{\$/€,t}$	15.1420	13	0.2986
H_2(m2)	$e_{\$/€,t}$ is exogenous to $CPI2_{¥,t}$	46.0577	13	0.0000
	$CPI2_{¥,t}$ is exogenous to $e_{\$/€,t}$	9.8996	13	0.7021
H_2(m3)	$e_{\$/€,t}$ is exogenous to $CPI3_{¥,t}$	18.0140	13	0.1570
	$CPI3_{¥,t}$ is exogenous to $e_{\$/€,t}$	17.4938	13	0.1777
H_3	$e_{\$/€,t}$ is exogenous to $CPI_{\$,t}$	15.3254	12	0.2241
	$CPI_{\$,t}$ is exogenous to $e_{\$/€,t}$	4.0296	12	0.9829
H_4(m1)	$e_{¥/€,t}$ is exogenous to $CPI1_{¥,t}$	19.2145	12	0.0835
H_5(m1)	$CPI1_{¥,t}$ is exogenous to $e_{¥/€,t}$	19.5070	12	0.0770
H_4(m2)	$e_{¥/€,t}$ is exogenous to $CPI2_{¥,t}$	30.9465	11	0.0011
H_5(m2)	$CPI2_{¥,t}$ is exogenous to $e_{¥/€,t}$	12.3088	11	0.3409
H_4(m3)	$e_{¥/€,t}$ is exogenous to $CPI3_{¥,t}$	15.2981	13	0.2891
H_5(m3)	$CPI3_{¥,t}$ is exogenous to $e_{¥/€,t}$	23.5885	13	0.0351