Is the Renminbi Undervalued?

An Empirical Study Based on the Balassa-Samuelson Effect

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China has experienced successful economic development over the past 30 years. Since a “reform and opening-up” policy was implemented in the late 1970s, China’s economic system has moved gradually from a centrally planned economy to a market economy. According to the World Bank’s database (2017), China’s nominal gross domestic product (GDP) boosted from USD 360.9 billion in 1987 to USD 11.2 trillion in 2016, and it ranks the second largest economy in the world only after the United States. In recent years, China’s currency, the renminbi (RMB), has been under the spotlight in the debate over the source of global current account imbalances. Based on the World Bank’s database (2017), China’s RMB appreciated over the past few years, and its nominal exchange rate (RMB per U.S. dollar) declined from 8.277 in 2004 to 6.644 in 2016. If China manipulates its currency and keeps it weak, the price level of Chinese products will remain at a low price level and become more competitive. As China’s largest trade partner, the United States claims that the RMB is significantly undervalued against the U.S. dollar, and the undervaluation of RMB plays an important role in enlarging the U.S. balance of trade deficit. President Donald Trump labeled China a “currency manipulator” and accused China of being the “grand champion” of currency manipulation.

In this paper, I use the purchasing power parity (PPP) approach to estimate the misalignment of Chinese RMB. The PPP approach is based on the relative PPP hypothesis, which states that measuring the long-run real exchange rates requires the estimation of the relationship between price levels and per capita real income. The Penn effect (Rogoff, 1996; Samuelson, 1964) posits that the price levels and per capita real income are positively correlated. The Balassa–Samuelson effect (Balassa, 1964; Samuelson, 1964), which predicts an upward sloping price–income relationship, offers a theoretical explanation for the Penn effect. In the PPP approach, as Rodrik (2008) claimed, the currency misalignments are the differences between a country's observed price level and its predicted price level.

In this research, I used the PPP approach to conduct a cross-country analysis to estimate currency misalignments because PPP is a general equilibrium approach that does not allow over- or undervaluation of any currency simultaneously (Lee, Ostry, Prati, Ricci, & Milesi-Ferretti, 2008). The most common way to analyze the price–income relationship is to regress countries' price levels on their per capita real income using a log-linear functional form. However, Hassan (2016) emphasized that the log-quadratic functional form is more suitable to estimate the price–income relationship. To get a more accurate estimate of the RMB misalignment, it would be better to use both the linear and quadratic functional forms and then to choose the results of the preferred functional form.

The PPP approach has been applied to analyze RMB misalignments in previous literature. Some of the literature argues that the RMB has been historically undervalued against the U.S. dollar. Frankel (2005) used cross-sectional data to suggest that the RMB was undervalued by 36% in 2000. Subramanian (2010) suggested that China's RMB was underestimated by about 31% against the U.S. dollar in 2005. Coudert and Couharde (2007) used the fundamental equilibrium exchange rate (FEER) method to calculate the real effective exchange rate; they found that China's RMB was undervalued between 2002 and 2005. Funke and Rahn (2004) focused on the behavioural equilibrium exchange rate and permanent equilibrium exchange rate models. They concluded that although the RMB is somewhat undervalued against the dollar, the misalignment is frequently exaggerated. Cline and

Williamson (2010) also used the FEER approach to assess the misalignment of the RMB, and their findings suggest that the RMB was undervalued by 41% in 2009.

However, other researchers obtained the opposite outcomes. For example, Zhang and Chen (2014) used a panel data set to estimate the RMB undervaluation; they claimed that after controlling net financial assets, the RMB was overvalued by about 10%–20% in 2011–2012. Cheung, Chinn, and Fujii (2007) also applied the PPP approach on panel data, and they did not find any evidence that the RMB was significantly undervalued in 2004. Almås, Grewal, Hvide, and Ugurlu (2017) estimated the price–income relationship by using the 2011 International Comparison Program cross-sectional data, and they concluded that there was no evidence of RMB undervaluation as of 2011.

This paper contributes to the ongoing debate over RMB's misalignments. First, I used the most recent data set of the Penn World Table (PWT) version 9.0, which covers 182 countries from 1950 to 2014 and provides reliable data of price level ratio and real GDP for each country across time. The features of the panel data allowed me to conduct this analysis in both cross-sectional and panel dimensions. Second, I applied different functional forms in my research, such as log-linear specification, log-quadratic specification, and fixed effects specification. Thus, my research provides a robust and comprehensive analysis that includes different functional forms, estimation methods, and types of data. More important, my research selected the preferred models using tools such as the Akaike information criterion (AIC), Bayesian information criterion (BIC), likelihood ratio test, and residual plots. The final results suggest that the preferred specifications provide no evidence for the alleged undervaluation of the Chinese RMB after 2011. On the contrary, there exists evidence that the Chinese RMB was actually overvalued by about 21% as of 2014.

The paper proceeds as follows: section II discusses the theory of the Balassa–Samuelson effect and summarizes the empirical methodology; section III describes the data of PWT 9.0, the outliers, and what insight the data gives us; and in section IV, I provide the results of both linear and quadratic functional form in a cross-section analysis. Then, I estimate the misalignment of the RMB based on the preferred model. In section V, I provide the results using panel analysis and the fixed effects model. Section VI concludes the paper by summarizing the main findings and discussing potential further research.

II. Empirical Methodology

PPP Approach and the Balassa–Samuelson Effect

I applied the PPP approach to estimate the misalignment of the Chinese RMB in this paper. Purchasing power parity is a theory that posits exchange rates between two currencies are in equilibrium when their purchasing power is the same in both countries. In other words, the exchange rate between two countries should equal the ratio of the two countries' price level of a fixed basket of goods and services (Katsioloudes & Hadjidakis, 2007). Measuring the long-run real exchange rates requires the analysis of the relationship between price levels and per capita real income. The Penn effect (Samuelson, 1994) estimates that the price levels are positively correlated with the per capita real income. Then, Balassa (1964) and Samuelson (1964) provided a theoretical explanation for the Penn effect and the deviation from PPP. Furthermore, they argued that differential productivity growth rates can explain the changes in real exchange rate in the long run. The economy consists of two sectors: the tradable sector, comprising manufactured goods that can be exported (e.g., computers), and the non-tradable sector, comprising mainly services that are delivered domestically (e.g., hairdressing). Additionally, the Balassa–Samuelson (1964) effect is based on several assumptions. First, the law of one price holds in the tradable sector, which means that the tradable goods must sell for the same price in all locations, but the price of non-tradable goods is determined domestically. Second, there exists perfect international capital mobility, which implies that there is no transaction or other costs in moving capital from one country to another. Third, the market is perfectly competitive. Fourth, the labour can move perfectly between the tradable and non-tradable sectors—that is, wages are paid at the marginal productivity and equalized across sectors.

Thanks to the rapid development of technology, labour productivity tends to rise more quickly in the manufacturing sector than in the service sector. The higher marginal productivity of tradable goods drives up the wage level for the tradable sector first; then, because of the domestic perfect labour mobility, the higher wage level in the tradable sector spreads out to the non-tradable sector. Afterward, the increased wage level for the non-tradable sector drives up the price of non-tradable goods. Because the aggregate price level is determined by the prices of both tradable and non-tradable goods, even if the price of tradable goods remains unchanged, the country still experiences an increase in its aggregate price level, which also means a real appreciation of its currency. As a result, the Balassa–Samuelson effect shows that a country's price level is positively correlated with the level of its income per capita (Penn effect). Therefore, the high-income countries tend to have a higher price level because of their higher tradable sector productivity, and there are deviations from PPP in this situation.[1]

Log-Linear Functional Form

As stated by Kenneth Rogoff (1996) in his paper "The Purchasing Power Parity Puzzle," one can use a log-linear regression to estimate the relationship between price levels and per capita real incomes. The linear functional form can be specified in Equation (1) as the following:

$$\boldsymbol{Log(PL_i) = \beta_0 + \beta_1 \log(RGDPC_i) + u_i} \tag{1}$$

where PL_i represents the price level of country i by that of the United States, and $RGDPC_i$ is the real per capita GDP for country *i*. The error term is represented by u_i.

[1] $q = \frac{ep*}{P} \neq 1$

The long-run real exchange rate misalignment can be estimated as the deviation from the estimated price level. Therefore, the percentage misalignment equals the difference between the log of observed price level(PL_i) and the log of predicted price level$\left(\widehat{PL_\iota}\right)$. It is presented as Equation (2):

$$\%\, \boldsymbol{misalignment} = \boldsymbol{Log}(\boldsymbol{PL_i}) - \boldsymbol{Log}\left(\widehat{\boldsymbol{PL_\iota}}\right) \qquad (2)$$

If the observed price level is higher than the predicted price level, the currency is considered overvalued, and vice versa. If there is no statistically significant difference between the observed and estimated price levels, one can conclude that the currency is not misaligned.

Log-Quadratic Functional Form

However, Hassan (2016) suggested, in his paper "The Price of Development: The Penn–Balassa–Samuelson Effect Revisited," that the relationship between price level and real income is not necessarily linear, and the correlation between price level and real income can be negative among undeveloped countries. Therefore, the log-linear functional form constructed by Rogoff (1996) can be improperly specified. To solve this problem, I estimated a log-quadratic functional form that confirms the non-monotonic pattern of price–income relationships; then, I compared its results with the results from the log-linear model. The specification of the quadratic model is shown in Equation (3) as the following:

$$\boldsymbol{Log}(\boldsymbol{PL_i}) = \boldsymbol{\beta_0} + \boldsymbol{\beta_1}\,\mathbf{Log}(\boldsymbol{RGDPC_i}) + \boldsymbol{\beta_2}\,\mathbf{log}(\boldsymbol{RGDPC_i})^{\mathbf{2}} + \boldsymbol{u_i}. \qquad (3)$$

Unlike the linear model, the quadratic model adds the squared term of log real per capita GDP. Then, it possible to analyze the model fit by checking residuals of the regression and conducting a log–likelihood ratio test. The null hypothesis of the log–likelihood ratio test is that the coefficient of the quadratic term equals zero. The quadratic model is preferred if one can reject the null hypothesis. In addition, information-based criteria, such as the AIC and the BIC, are also useful tools to analyze the model's goodness of fit. The model that yields the lowest information criteria is the preferred model.

Cross-section dimension & Panel dimension

This paper provides two different analyses: the cross-sectional analysis and the panel analysis. In the cross-sectional analysis, I performed the regression using both the log-linear and log-quadratic specifications. Then, I identified the preferred functional form. The RMB misalignments was estimated based on the preferred specification. In the panel analysis, I not only performed the regression using the log-linear and log-quadratic specifications but also controlled the year dummies and the unobservable country-specific fixed effects. In this case, I investigated only the within-country variation. Finally, the RMB misalignments was estimated using the preferred functional form with year dummies and fixed effects.

III. Data

I used the panel data of Penn World Table version 9.0 (PWT 9.0) in this paper. PWT 9.0 is named for its original developers at the University of Pennsylvania: Robert Summers, Irving Kravis, and Alan Heston. Currently, this data set is maintained by the University of California, Davis, and the Groningen Growth Development Centre of the University of Groningen. It covers information on relative levels of income, output, input, population, and productivity from 182 countries from 1950 to 2014.

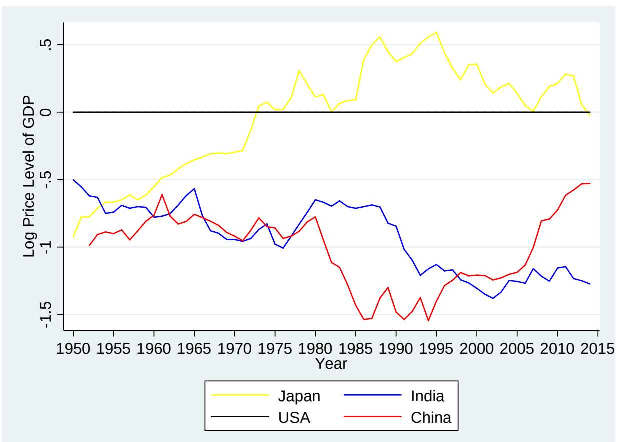

Figure 1. Log Price Level Relative to the US

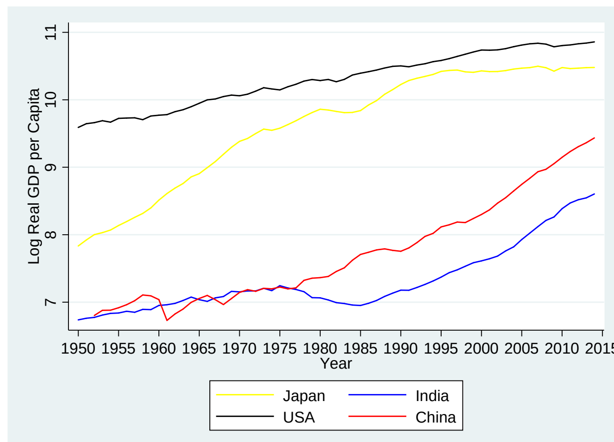

Figure 2. Log Real GDP

Figure 1 shows the log price level of Japan, the United States, China, and India. Figure 2 plots the change of the log real per capita GDP across time for these countries. Japan, the United States, and China experienced a constant growth in per capita GDP after the 1980s. India's per capita GDP fell slightly at the beginning of the 1980s, but it has been constantly increasing since 1985. However, Figure 1 demonstrates that the price levels were not changing monotonically, especially for developing countries such as China and India. These two figures gave me insight into how price level changes with the increase of real GDP. Hassan's (2016) finding that the price–income relationship is nonlinear could be correct.

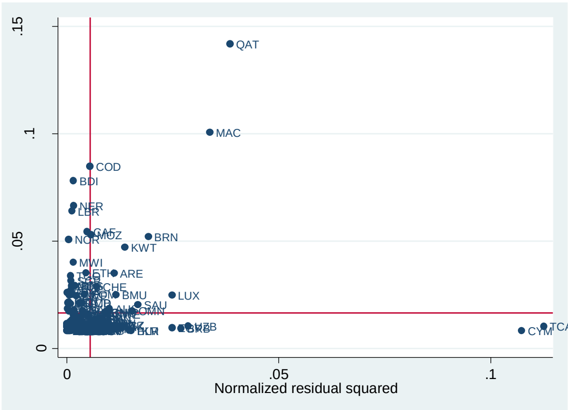

Figure 3. Leverage versus Residual Squared

Figure 4. DFBETA for Log Real GDP

Before conducting the results of the formal analysis, it is necessary to get rid of the outliers. I preformed the regression using the quadratic equation (3) on 2011 cross-sectional data. Figure 3 depicts the leverage versus residual squared plot. Points to the right of the vertical line have larger-than-average residuals, and points above the horizontal line have higher-than-average leverage. Figure 3 demonstrates that countries such as Cayman Islands (CYM) and Turks and Caicos Islands (TCA) have very large residuals. In addition, Qatar (QAT) and Macau (MAC) have both high leverage and large residuals. Besides, the DFBETA plot of Figure 4 identifies the most influential observations. The horizontal lines represent the cut-off value (2/sqrt(182)) for DFBETAs, where 182 is the number of observations. Then, one can see that oil-exporting countries such as Qatar (QAT), Kuwait (KWT), Brunei (BRN), and the United Arab Emirates (ARE) are outliers. Additionally, microstates such as Macau (MAC), Turks and Caicos Islands (TCA), and Cayman Islands (CYM) are also outliers. Overall, I decided to exclude the observations of microstates with less than 1.3 million people, and I excluded four oil-exporting countries: Saudi Arabia, United Arab Emirates, Kuwait, and Qatar.

Moreover, I collected the price level data in this paper by dividing the price level of each country's gross domestic product by that of the United States. I obtained the income per capita by dividing the output-side real GDP by countries' total populations.[2] Then, I log transformed both the dependent (i.e., price level) and independent (i.e., real per capita GDP) variables. In the next two sections, I used the PWT 9.0 to produce the linear and quadratic estimations in both cross-sectional and panel dimensions.

[2] RGDPC = $\frac{\text{rgdpo}}{\text{pop}}$ = income per capita

IV. Cross-sectional Analysis

In this section, I analyzed the price–income relationship in a cross-sectional dimension and performed a robust OLS estimation for each year separately from 2004 to 2014. Table 1 presents the estimation results using the log-linear functional form (1). Column 1 indicates that the coefficient of log real per capita GDP is positive (around 0.25) and statistically significant (P values < 0.001) for each year from 2004 to 2014. The price–income relationship is constantly positive, and as the income increases, the price level also increases. The adjusted R-squared vary from 0.370 to 0.558, which means that around 45% of the variance is explained by the linear model. Figure 5 graphically represents the linear regression for 2014, which is also the most recent year in PWT 9.0 in a cross-section of 122 countries. This 2014 cross-sectional data regression yields a significant (P values < 0.001) coefficient of 0.248 on the log of real per capita GDP. In other words, every 1% increase in real per capita GDP is associated with 0.248% in real appreciation. Overall, the linear functional form estimation results reveal that the Balassa–Samuelsson effect exists regardless of the country's income level.

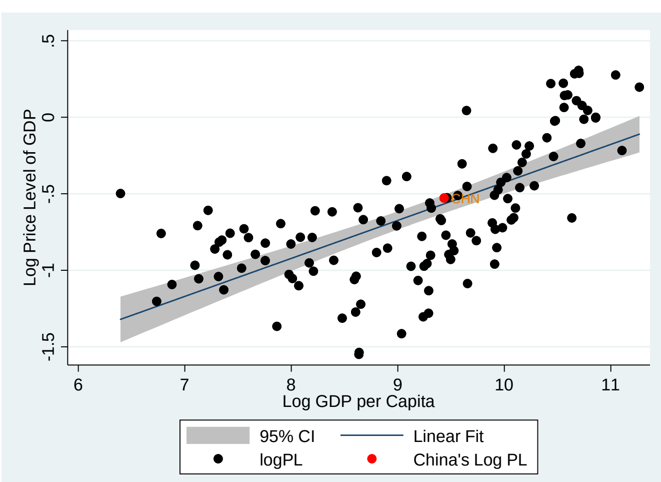

Figure 5. Linear Form (2014) –
Linear Fit with 95% confidence interval

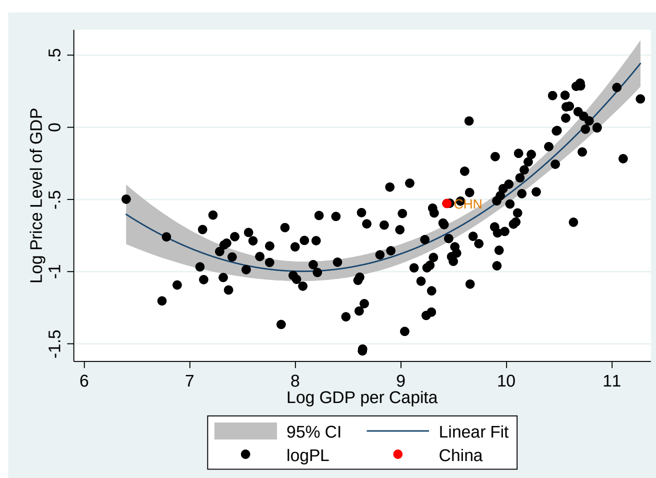

Figure 6. Quadratic Form (2014) –
Quadratic Fit with 95% confidence interval

TABLE 1

ESTIMATION RESULTS OF LINEAR FUNCTIONAL FORM (CROSS-SECTIONAL)

YEAR	LOG(RGDPC$_I$)	CONSTANT	ADJUSTED R^2	OBSERVATIONS
	(1)	(2)	(3)	(4)
2004	0.319*** (0.026)	-3.535*** (0.234)	0.549	122
2005	0.308*** (0.025)	-3.448*** (0.223)	0.558	122
2006	0.276*** (0.031)	-3.146*** (0.281)	0.487	122
2007	0.260*** (0.034)	-2.941*** (0.311)	0.459	122
2008	0.245*** (0.034)	-2.735*** (0.318)	0.428	122
2009	0.227*** (0.036)	-2.646*** (0.333)	0.370	122
2010	0.256*** (0.028)	-2.929*** (0.257)	0.468	122
2011	0.268*** (0.027)	-3.021*** (0.251)	0.486	122
2012	0.255*** (0.025)	-2.940*** (0.232)	0.483	122
2013	0.256*** (0.025)	-2.957*** (0.230)	0.491	122
2014	0.248*** (0.026)	-2.909*** (0.241)	0.449	122

*, ** and *** indicate statistical significance at 10%, 5% and 1% percent levels, respectively
Robust standard errors in parentheses

TABLE 2

ESTIMATION RESULTS OF QUADRATIC FUNCTIONAL FORM (CROSS-SECTIONAL)

YEAR	$\log(\mathrm{RGDPC_i})$	$\log(\mathrm{RGDPC_i})^2$	CONSTANT	Adjusted R^2	OBSERVATIONS
	(1)	(2)	(3)	(4)	(5)
2004	-1.767*** (0.342)	0.120*** (0.020)	5.387*** (1.472)	0.654	122
2005	-1.662*** (0.319)	0.112*** (0.018)	5.025*** (1.380)	0.663	122
2006	-1.906*** (0.293)	0.125*** (0.017)	6.206*** (1.267)	0.648	122
2007	-2.005*** (0.273)	0.129*** (0.016)	6.772*** (1.181)	0.655	122
2008	-2.150*** (0.266)	0.137*** (0.015)	7.554*** (1.153)	0.658	122
2009	-2.526*** (0.257)	0.158*** (0.015)	9.133*** (1.112)	0.677	122
2010	-2.260*** (0.276)	0.143*** (0.016)	7.960*** (1.202)	0.685	122
2011	-2.336*** (0.288)	0.147*** (0.016)	8.331*** (1.267)	0.693	122
2012	-2.282*** (0.281)	0.142*** (0.016)	8.160*** (1.240)	0.691	122
2013	-2.109*** (0.284)	0.132*** (0.016)	7.418*** (1.254)	0.676	122
2014	-2.273*** (0.299)	0.141*** (0.017)	8.173*** (1.325)	0.653	122

*, ** and *** indicate statistical significance at 10%, 5% and 1% percent levels, respectively
Robust standard errors in parentheses

However, the non-monotonic estimation (U-shaped curve) in Figure 6 shows that the linear relation of price level and incomes is suspicious. It is possible that the Balassa–Samuelsson effect does not hold in all the countries. Table 2 presents the results of the regression using the log-quadratic functional form (3). Column 1 indicates that the coefficients of log real per capita GDP are negative (around -2.1) and statistically significant (*P* values < 0.001) for each year from 2004 to 2014. More important, the coefficients of squared log per capita real GDP are positive (around 0.14) and statistically significant (*P* values < 0.001) for each year from 2004 to 2014. These results suggest that the price–income relationship is non-monotonic. The price level increases as the real GDP increases in middle- and high-income countries. However, in low-income countries, the price level decreases as the real GDP increases. The adjusted R-squared varies from 0.648 to 0.691. For each year, the adjusted R-squared of the regression with a quadratic term is greater than the regression without a quadratic term. Thus, the non-monotonic model fits better, and around 65% of the variance was explained by the quadratic functional model. Figure 6 graphically represents the regression of the quadratic model for the year 2014 on a cross-section of 122 countries. The regression yields a significant coefficient of -2.273 on the log of real per capita GDP and a significant coefficient of 0.141 on the squared log of real per capita GDP. These coefficients suggest that the price–income relationship is quadratic, and as the income grows, the poor countries' currency depreciates initially (without the Balassa–Samuelsson effect) but gradually appreciates later (with the Balassa–Samuelsson effect).

After determining the estimation results in a cross-sectional dimension, I went a further step to estimate whether the RMB was undervalued. The estimated values using the linear form and the quadratic form are reported in Table 3 and Table 4, respectively. In column 1, $\mathrm{Log}(PL_I)$ stands for China's actual log of price level. In column 2, $\mathrm{Log}\left(\widehat{PL_I}\right)$ represents the estimated log of China's price level. The 95% confidence intervals of the estimated log of price level for China are presented in column 3. Finally, I calculated the percentage of the misalignment of the RMB as the difference between the observed price level and the predicted price level if the difference is statistically significant.

In Table 3, for the year 2004, the log of price level predicted for China by the linear equation is -0.779, with a 95% confidence interval (-0.842, -0.715). China's actual log of price level is -1.202. In other words, the difference between the observed and the predicted price levels suggests that the RMB was undervalued by 42.3% compared to the U.S. dollar as of 2004. The difference between the observed and the predicted price levels remains statistically significant before 2012. Since 2012, the observed price level for China falls within the 95% confidence interval of the predicted price level; hence, the RMB is not undervalued. Figure 7 graphically represents these results and makes clear that the real appreciation of the RMB has grown faster than expected.

Table 4 demonstrates the estimated values for China using the log-quadratic equation (3). For the year 2004, the predicted log of price level is -0.958, with a 95% confidence interval (-1.038, -0.878). The observed log of price level (-1.202) is located outside the confidence interval of the predicted price level, which means that the misalignment is statistically significant and the RMB was undervalued by 24.4% compared to the U.S. dollar as of 2004. The non-monotonic regression provides a lower RMB misalignment than the regression of the linear model. The estimated real undervaluation of RMB declined constantly after 2005. From 2008 to 2010, the observed price level of China falls within the 95% confidence interval of the predicted price level; thus, the RMB was not undervalued significantly during these years. After 2011, the observed price level of China became higher than the predicted price level, and the misalignment of RMB is significant. In 2014, the RMB was overvalued by about 20.8% compared to the U.S. dollar. Figure 8 plots China's actual price level and estimated price level with its 95% confidence intervals. Again, the real appreciation of the RMB developed faster than expected.

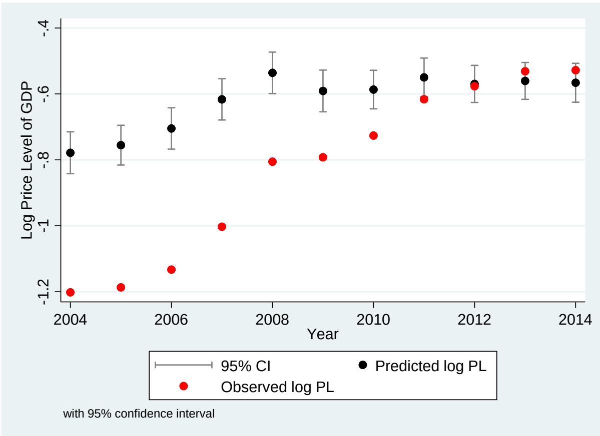

Figure 7. Linear Form - Observed and Predicted Price Level of China

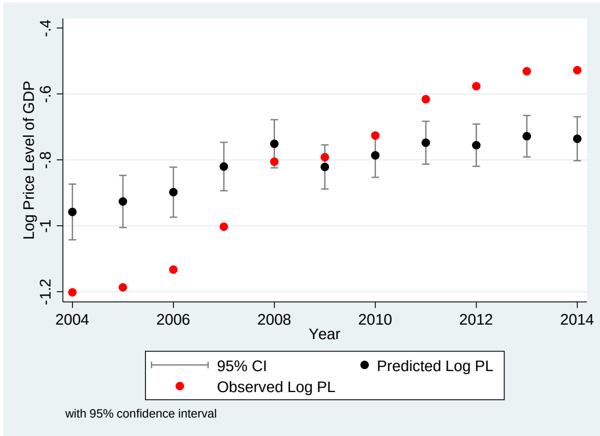

Figure 8. Quadratic Form - Observed and Predicted Price Level of China

Therefore, if one analyzed only the outcomes of the linear functional form, one would conclude that the RMB was undervalued against the U.S. dollar before 2012, but there was no misalignment after 2012. However, after controlling the quadratic term of real per capita GDP, I determined that the real undervaluation of RMB only existed before 2008 but was overvalued since 2011.

TABLE 3

ESTIMATION OF MISALIGNMENT USING LINEAR CROSS-SECTIONAL DATA MODEL

YEAR	$\mathrm{LOG}(PL_I)$	$\mathrm{LOG}(\widehat{PL_I})$	95% CI OF $\mathrm{LOG}(\widehat{PL_I})$	%MISALIGNMENT
	(1)	(2)	(3)	(4)
2004	-1.202*	-0.779	(-0.842, -0.715)	-42.3%
2005	-1.187*	-0.755	(-0.815, -0.695)	-43.1%
2006	-1.133*	-0.705	(-0.767, -0.642)	-42.8%
2007	-1.003*	-0.616	(-0.680, -0.553)	-38.6%
2008	-0.805*	-0.536	(-0.599, -0.473)	-26.9%
2009	-0.792*	-0.591	(-0.656, -0.526)	-20.1%
2010	-0.726*	-0.587	(-0.646, -0.528)	-13.9%
2011	-0.616*	-0.550	(-0.609, -0.491)	-6.6%
2012	-0.577	-0.570	(-0.626, -0.513)	No misalignment
2013	-0.531	-0.560	(-0.616, -0.505)	No misalignment
2014	-0.528	-0.566	(-0.625, -0.507)	No misalignment

*The observed value is significantly different from the expected value at 95% confidence interval

TABLE 4

ESTIMATION OF MISALIGNMENT USING QUADRATIC CROSS-SECTIONAL DATA MODEL

YEAR	$\mathrm{LOG}(PL_I)$	$\mathrm{LOG}(\widehat{PL_I})$	95% CI OF $\mathrm{LOG}(\widehat{PL_I})$	%MISALIGNMENT
	(1)	(2)	(3)	(4)
2004	-1.202*	-0.958	(-1.038, -0.878)	-24.4%
2005	-1.187*	-0.926	(-1.001, -0.851)	-26.1%
2006	-1.133*	-0.898	(-0.971, -0.825)	-23.5%
2007	-1.003*	-0.820	(-0.890, -0.751)	-18.3%
2008	-0.805	-0.751	(-0.819, -0.684)	No misalignment
2009	-0.792	-0.821	(-0.884, -0.759)	No misalignment
2010	-0.726	-0.786	(-0.849, -0.724)	No misalignment
2011	-0.616*	-0.748	(-0.810, -0.685)	13.2%
2012	-0.577*	-0.756	(-0.815, -0.696)	17.9%
2013	-0.531*	-0.728	(-0.788, -0.669)	19.7%
2014	-0.528*	-0.736	(-0.797, -0.675)	20.8%

*The observed value is significantly different from the expected value at 95% confidence interval

Because the linear and quadratic forms yield different results, I needed to determine which one better presents the price–income relationship. Figures 9 and 10 display the plots of residuals versus real per capita GDP from the regression using the linear form and the quadratic form, respectively. Figure 9 shows that the residuals have a nonlinear relationship with real per capita GDP. However, after controlling the squared term, Figure 10 indicates that the residuals do not have a significant relationship with real per capita GDP. Thus, the log-quadratic functional form is better than the log-linear functional form.

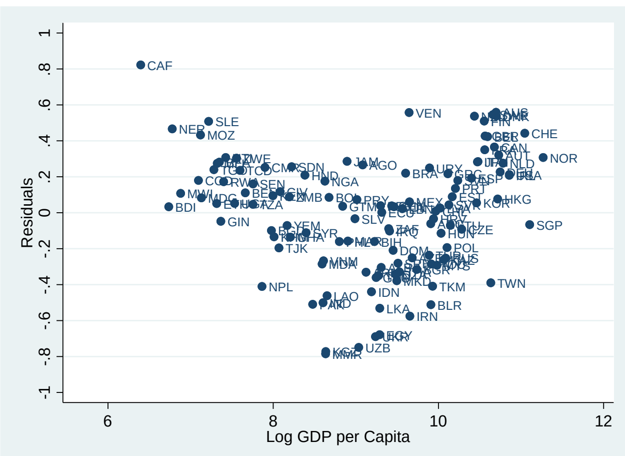

Figure 9. Linear Form (2014) – Residuals versus per Capita Real GDP

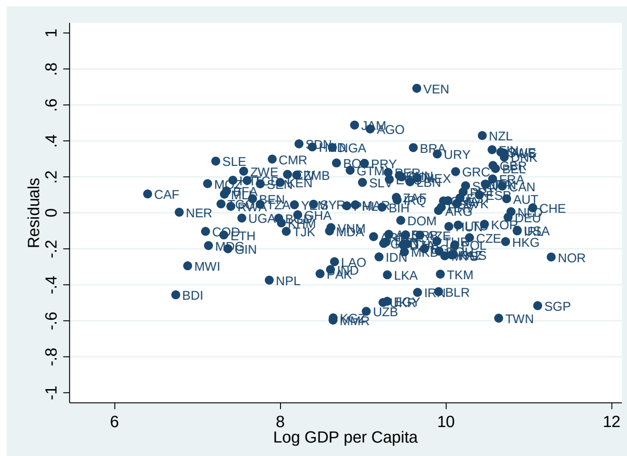

Figure 10. Quadratic Form (2014) – Residuals versus per Capita Real GDP

In addition, the log-likelihood ratio test can be used for comparing the goodness of fit of the two statistical models. The null model in the likelihood-ratio test is the restricted form of the alternative model. In this paper, the null model is the log-linear functional model (1) because this model assumes the coefficient of the quadratic term equals zero and can be treated as the restricted form of the quadratic functional model (3).

$$\boldsymbol{H_o = Restricted\ model\ (Linear\ form)}$$

$$\boldsymbol{H_1 = Unrestricted\ model\ (Quadratic\ form)}$$

The results of the likelihood-ratio test are reported in columns 1 and 2 of Table 5. The log-likelihood ratio statistics in column 1 have approximately X^2 distribution. The *P* values in column 2 suggest that the null model is rejected (*P* values < 0.000). As a result, the log-likelihood ratio test suggests that, at a 95% confidence level, there is no evidence that the coefficient of the quadratic term is zero; hence, the quadratic model is my preferred model.

Additionally, I used the AIC and the BIC as criteria for model selection—the smaller the AIC and BIC, the better the model. Columns 3–6 of Table 5 summarize the results of the AICs and BICs. The quadratic functional form (3) consistently produced smaller AICs and BICs. Both criteria suggest that the quadratic functional form is better than the linear functional form.

Overall, the residual plots, likelihood-ratio tests, AICs, and BICs all suggest that the quadratic functional form is the better functional form. Thus, I conclude that the real appreciation of the RMB has grown faster than expected in general. Based on the cross-sectional analysis, the RMB was undervalued against the U.S. dollar before 2008 but overvalued since 2011, and the real overvaluation increased to about 20.8% as of 2014.

TABLE 5

CIA, BIC AND LIKELIHOOD-RATIO TEST (CROSS-SECTIONAL)

	LIKELIHOOD-RATIO		AIC		BIC	
	LR CHI2(1)	PROB > CHI2	LINEAR	QUADRATIC	LINEAR	QUADRATIC
	(1)	(2)	(3)	(4)	(5)	(6)
2004	33.36	0.00	95.642	64.283	101.250	72.695
2005	34.14	0.00	83.723	51.585	89.332	59.998
2006	46.87	0.00	93.866	49.000	99.474	57.413
2007	55.96	0.00	95.875	41.911	101.483	50.323
2008	63.73	0.00	96.175	34.444	101.783	42.856
2009	82.54	0.00	101.312	20.775	106.921	29.187
2010	65.00	0.00	77.829	14.826	83.437	23.238
2011	63.89	0.00	77.013	15.126	82.621	23.538
2012	63.74	0.00	65.072	3.331	70.680	11.743
2013	56.29	0.00	61.826	7.536	67.434	15.949
2014	57.27	0.00	73.396	18.121	79.004	26.533

V. Panel Dimension Analysis

In this section, I analyzed the price–income relationship in a panel dimension by using PWT 9.0, which covers 182 countries from 1950 to 2014. Table 6 presents the estimation results from the panel dimension analysis. Column 1 reports the estimation results that I conducted using the log-linear functional equation (1) with the inclusion of the year dummies. This regression yields a significant (*P* values < 0.001) coefficient of 0.207 on the log of real per capita GDP. Specifically, every 1% increase in real per capita GDP is associated with 0.207% in real appreciation. These results confirm the positive price–income relationship predicted by the Balassa–Samuelsson effect regardless of the country's income level. The adjusted R-squared of the linear specification model is 0.440, which means that around 44% of the per capita GDP variation is explained by the linear model. Figure 11 graphically represents the linear regression of equation (1) on a panel of 122 countries from 1950 to 2014.

Nevertheless, the quadratic regressions in Table 6 demonstrate once again that the price–income relation is non-monotonic even in a longitudinal dimension. Figure 12 reveals the estimated quadratic curve without the fixed effects; in addition, the actual values of China are marked with red dots. Apparently, the Balassa–Samuelson effect holds only for middle- and high-income countries, but in low-income countries, the price–income relationship is negative. In the case of China (red dots), its actual values are consistent with the non-monotonic pattern, which is developed along the curve from the downward-sloping arm to the upward-sloping arm. Figure 13 shows the locally weighted scatterplot smoothing (LOWESS) curve. The LOWESS estimation reinforces the point that the relationship between price level and real per capita GDP is quadratic (U-shaped curve).

TABLE 6

ESTIMATION RESULTS OF PANEL ANALYSIS

YEAR	LINEAR	QUADRATIC	QUADRATIC
	(1)	(2)	(3)
$Log(RGDPC_i)$	0.207*** (0.005)	-2.335*** (0.070)	-2.5693*** (0.359)
$Log(RGDPC_i)^2$		0.150*** (0.004)	0.149*** (0.020)
Constant	-2.067*** (0.082)	8.564*** (0.306)	10.296*** (1.583)
Adjusted R^2	0.440	0.446	0.304
Observations	6471	6471	6471
Year Dummies	YES	YES	YES
Country Fixed Effects	NO	NO	YES

*, ** and *** indicate statistical significance at 10%, 5% and 1% percent levels, respectively
Robust standard errors in parentheses

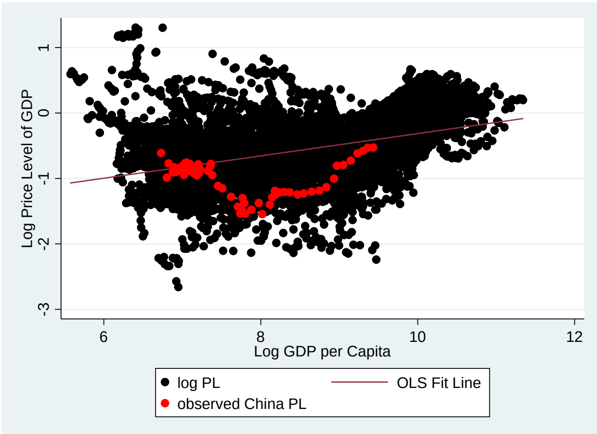

Figure 11. Linear Form (Panel) – Linear Fit

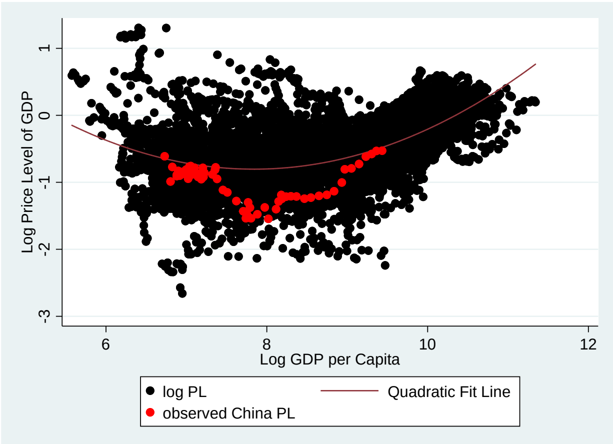

Figure 12. Quadratic Form Without Fixed Effects (Panel) – Quadratic Fit

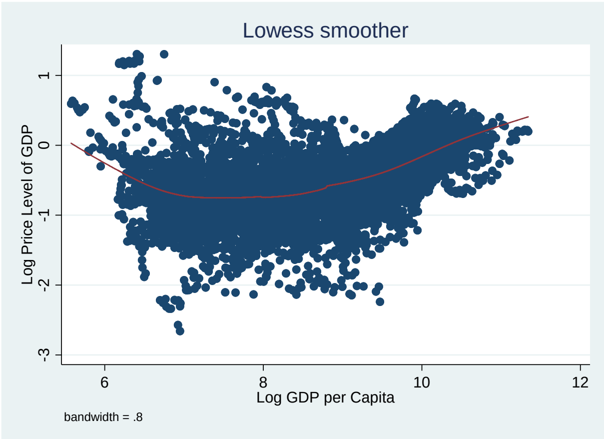

Figure 13. Locally Weighted Scatterplot Smoothing (Panel)

Columns 2 and 3 of Table 6 present the non-monotonic estimations. Column 2 provides the estimation results using the log-quadratic functional form (3) with the control of year dummies. It indicates that the coefficient of log real per capita GDP is negative (-2.335) and statistically significant (P values < 0.001); moreover, the coefficient of log-squared real per capita GDP is positive (0.150) and statistically significant (P values < 0.001). These estimation results are consistent with the U-shaped curve in Figures 12 and 13. The quadratic model fit slightly better than the linear model, as indicated by the adjusted R-squared increase from 0.440 to 0.446. Overall, when I allowed non-monotonic regression, the Balassa–Samuelsson effect was only displayed in middle- and high- income countries.

However, some unobservable, time-invariant country characteristics, such as culture, history, and institutions, are systematically different across countries. These characteristics are unobservable but are correlated with the real per capita GDP and can bias the price–income relationship. Therefore, I conducted a within-country analysis, which controlled the country-specific fixed effects. Column 3 of Table 6 presents the regression estimation results by using the log-quadratic functional form (3) with the inclusion of year dummies and country-specific fixed effects. These results indicated that the coefficient of log real per capita GDP is negative (-2.5693) and statistically significant (P values < 0.001); furthermore, the coefficient of log-squared real per capita GDP is positive (0.149) and statistically significant (P values < 0.001). Therefore, the quadratic relationship between the price level and income holds again for the sample using country-specific fixed effects. In other words, even when I investigated only the within-country variation, the price–income relationship remained non-monotonic. These results affirm the previous conclusion drawn by Hassan (2016) that a non-monotonic Balassa–Samuelson effect is a general pattern that holds true throughout the world. Additionally, this conclusion holds in the cross-sectional analysis, the panel analysis, and the within-country analysis.

After getting the estimation results in the panel dimension, I analyzed whether the RMB was devaluated from 2004 to 2014. The Balassa–Samuelsson effect appeared in China during this period, as indicated by the price level increase with the increase in income. Table 7 gives China's estimated price levels by applying the quadratic functional form (3) with the control of year dummies and country-specific fixed effects. For 2004, China's actual log of price level was -1.202 and its predicted log of price level was -0.942, with a 95% confidence interval (-1.035, -0.847). As a result, the difference between the observed and the predicted price levels suggests a 26.0% real undervaluation of the Chinese RMB against the U.S. dollar as of 2004; more important, this real undervaluation is significant. The difference between the observed and predicted price levels is shrinking over time, but it remained statistically significant before 2008. In 2008–2010, China's observed price levels fell within the 95% confidence interval of the predicted price levels; therefore, the RMB misalignments were not statistically significant. After 2010, the RMB overvaluation was estimated as statistically significant, and the magnitude of real overvaluation increased constantly. In 2011, the last year recorded in PWT 9.0, the predicted log of price level was -0.736, with a 95% confidence interval (-0.820, -0.652). The difference between this estimated price level and the observed price level (-0.616) suggests a 12.0% real overvaluation of the Chinese RMB compared to the U.S. dollar as of 2011. Additionally, the real overvaluation of the Chinese RMB mounted to around 21% in both 2013 and 2014. Figure 14 plots the actual and predicted price levels with their 95% confidence intervals from 2004 to 2014. These results are similar to the estimated RMB misalignments from the cross-sectional analysis in section IV.

TABLE 7

ESTIMATION OF MISALIGNMENT USING QUADRATIC REGRESSION WITH FIXED EFFECTS AND YEAR DUMMIES

YEAR	$\text{LOG}(PL_I)$	$\text{LOG}(\widehat{PL_I})$	95% CI OF $\text{LOG}(\widehat{PL_I})$	%MISALIGNMENT
	(1)	(2)	(3)	(4)
2004	-1.202*	-0.942	(-1.035, -0.847)	-26.0%
2005	-1.187*	-0.928	(-1.020, -0.835)	-25.9%
2006	-1.133*	-0.893	(-0.986, -0.799)	-24.0%
2007	-1.003*	-0.816	(-0.911, -0.722)	-18.7%
2008	-0.805	-0.732	(-0.827, -0.638)	No misalignment
2009	-0.792	-0.787	(-0.876, -0.698)	No misalignment
2010	-0.726	-0.777	(-0.863, -0.692)	No misalignment
2011	-0.616*	-0.736	(-0.820, -0.652)	12.0%
2012	-0.577*	-0.753	(-0.838, -0.669)	17.7%
2013	-0.531*	-0.742	(-0.828, -0.657)	21.1%
2014	-0.528*	-0.743	(-0.829, -0.657)	21.5%

*The observed value is significantly different from the expected value at 95% confidence interval.

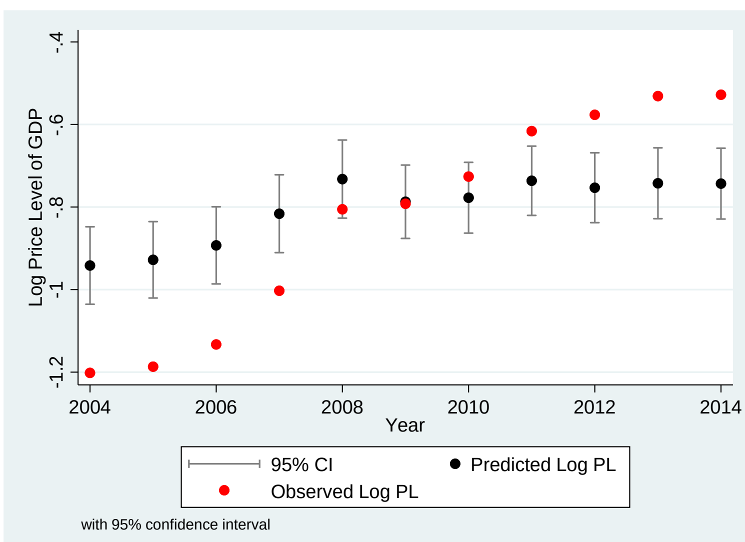

Figure 14. Quadratic Fixed Effects model – Observed and Predicted Price Level of China

VI. Conclusion

In this paper, I analyzed the alleged undervaluation of the Chinese RMB against the U.S. dollar by revisiting the PPP approach. This approach measures long-run real exchange rates by analyzing the relationship between price levels and per capita real income. I used the most recent PWT 9.0 data to conduct the estimation results.

In the cross-sectional analysis, I performed the robust OLS estimation for each year separately in 2004–2014. The results of the standard simple linear regression reveal that the RMB was undervalued by 42.3% against the U.S. dollar as of 2004. The real undervaluation remains statistically significant before 2012. Since 2012, the RMB has been neither undervalued nor overvalued. However, the non-monotonic regression indicates that the Balassa–Samuelsson effect only appears in middle- and high-income countries. The estimated real undervaluation of the RMB declined constantly after 2005. From 2008 to 2010, the RMB was neither undervalued nor overvalued. After 2010, the RMB has been significantly overvalued. In 2014, the RMB was overvalued by about 20.8% against the U.S. dollar. Overall, in the cross-sectional analysis, the residual plots, likelihood-ratio tests, AICs, and BICs all suggest that the non-monotonic regression is the preferred model.

In the panel analysis, I performed a robust estimation on the panel dimension that includes 182 countries from 1950 to 2014. The estimation results using the log-quadratic functional form with the inclusion of year dummies and country-specific fixed effects indicate that the Balassa–Samuelson effect holds only for middle- and high-income countries. In other words, even when I investigated only the within-country variation, the price–income relationship remained non-monotonic. For 2004, there was a 26.0% real undervaluation of the Chinese RMB compared to the U.S. dollar. From 2008 to 2010, the RMB was neither undervalued nor overvalued. After 2010, the RMB was estimated as statistically significantly overvalued, and the magnitude of real overvaluation increased consistently. Additionally, the real overvaluation of the Chinese RMB mounted to around 21% in both 2013 and 2014.

To summarize, when I allowed non-monotonic regression, no matter whether the analysis was conducted in cross-sectional or panel dimensions, the price–income relationship was a U-shaped curve and the Balassa–Samuelson effect was evident in middle- and high-income countries. The alleged undervaluation of the RMB only appeared before 2008. Since 2011, the RMB has been significantly overvalued, and the RMB was overvalued by about 21% against the U.S. dollar as of 2014. These results are robust and consistent across cross-sectional and panel dimensions. As a result, I have determined that the global current account imbalances are not caused by the undervaluation of the Chinese RMB.

Potential future analyses could concentrate on the real overvaluation of the RMB. It would be interesting to investigate the true cause of this type of real overvaluation and its effect on international trade. Furthermore, the Chinese government is currently promoting the process of the RMB’s internationalization and seeks to make the RMB a major investment and reserve currency in the international monetary system. In fact, the RMB officially joined the International Monetary Fund’s special drawing right basket of currencies on October 1, 2016. Therefore, the factors of the RMB’s internationalization could be taken into consideration in the future debate of the RMB valuation.

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