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Estimating Currency Misalignment Using the Penn Effect: It's Not as Simple As It Looks
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## ABSTRACT

We investigate the strength of the Penn effect in the most recent version of the Penn World Tables (PWTs). We find that the earlier findings of a Penn effect are confirmed, but that there is some evidence for nonlinearity. Developed and developing countries display different types of nonlinear behaviors. The nonlinear behaviors are likely attributable to differences across countries and do not change when additional control variables are added. We confirm earlier findings of large RMB misalignment in the mid-2000's, but find that by 2011, the RMB seems near equilibrium. While the Penn effect is quite robust across datasets, estimated misalignment can noticeably change from a linear to a nonlinear specification, and from dataset to dataset.

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## 1. Introduction

The issue of currency misalignment is a perennial one. As long as countries strive to reallocate aggregate demand in their own favor, disputes will arise regarding the degree to which currency values are "fair". The problem, of course, is what constitutes such a fair value; each different model yields its own valuation.

One key strand of methodologies involves the comparison of price levels as a means of inferring the proper currency value. Absolute purchasing power parity is one particularly simple, and particularly inappropriate, price criterion. After all, the proposition that similar bundles of goods should be equally priced when denominated in a common currency is one of the most frequently violated ones.

A more commonly used criterion is the Penn Effect. One of the most well-documented empirical regularities in the international finance literature, the finding that the price level is higher in countries with a higher per capita income is consistent with a variety of theoretical frameworks, including a Balassa-Samuelson mechanism, and demand side forces including a preference for nontradable goods at higher incomes (i.e., non-homotheticity).[1]

In this paper we seek to document whether indeed the Penn effect is as robust as is typically conceived. In particular, testing for the Penn effect has been hampered by the imprecision with which the price data are measured. This means that new versions of the data set can lead to substantially different results.[2] Further, we investigate the presence of a non-linear Penn effect; a quadratic link between income and real exchange rate.

[1] The necessary conditions for demand side factors to matter are laid out in De Gregorio, et al. (1994).
[2] See Chen and Ravallion (2010) for discussion of how the estimated Penn effect various over the different vintages of the International Comparison Project based data sets. Estimates of misalignment also vary depending on vintage, as shown by Cheung, et al. (2007).

To anticipate our results, we find that the elasticity of the relative price level to per capita income is fairly consistently estimated, across data sets. However, there is some evidence that the relationship is nonlinear; a statistically significant quadratic term, implying a U-shaped relationship, is estimated.

The nature of the nonlinearity displayed by the developed and developing economies differs. For the developed economies, the quadratic term implies an inverted U-shaped relationship between real exchange rate and income. The developing economies, on the other hand, display a U-shaped relationship. Additional analyses suggest that the nonlinearity is likely driven by variation across countries rather than by variation within a country. The estimated quadratic term is robust to the addition of select economic covariates in the regressions.

The inclusion of a significant quadratic term, unsurprisingly, has implications for the magnitude of the estimated degree of misalignment. We focus on the example of China as a means of highlighting the point. In terms of the Chinese currency – the renminbi (RMB), it appears that the RMB was fairly valued by 2011. In contrast, the RMB's value was undervalued in 2005, and overvalued in 2014 if, for instance, one uses a one standard error threshold, not so if one uses a conventional two standard error convention. Hence, depending on one's perspective regarding the proper significance level to apply to policy questions, the deviation was statistically significant (Frankel, 2006) or not (Cheung et al., 2007).

## 2. Background

At the heart of the debate over the right way of determining the appropriate exchange rate level are contrasting ideas of what constitutes an equilibrium exchange rate, what time frame the equilibrium condition pertains to, and, not least, what econometric method to implement.

Most of the extant studies fall into some familiar categories, either relying upon some form of relative purchasing power parity (PPP) or cost competitiveness calculation, the modeling of deviations from absolute PPP, a composite model incorporating several channels of effects (sometimes called behavioral equilibrium exchange rate models), or flow equilibrium models. These alternative approaches are reviewed in, for example, Cheung et al. (2007, 2010a).

In this study, we appeal to a simple, and apparently robust, relationship between the real exchange rate and *per capita* income. We then elaborate the analysis by stratifying the data by level of income, and by adding in other variables that might alter one's assessment of the fundamental equilibrium level of the exchange rate.[3]

First, we consider the basic framework of analysis. Consider the law of one price, which states that the price of a single good should be equalized in common currency terms (expressed in logs):

$$p_{i,t} = s_t + p_{i,t}^* \tag{1}$$

where $s_t$ is the log exchange rate, $p_{i,t}$ is the log price of good *i* at time *t*, and the asterisk denotes the foreign country variable. Summing over all goods, and assuming the weights associated with each good are the same in both the home country and foreign country basket, one then obtains the absolute purchasing power parity condition:

$$p_t = s_t + p_t^* \tag{2}$$

[3] Dunaway, et al. (2009) conduct an extensive analysis, highlighting the sensitivity of the results to differing assumptions.

where for simplicity assume *p* is a arithmetic average of individual log prices. As is well known, if the weights differ between home and foreign country baskets (let's say production bundles), then even if the law of one price holds, absolute purchasing power parity need not hold.

The "price level" variable in the PWTs (Summers and Heston, 1991), and other purchasing power parity exchange rates, attempt to circumvent this problem by using *prices* (not price indices) of goods, and calculating the aggregate price level using the same weights. Assume for the moment that this can be accomplished, but that some share of the basket (α) is nontradable (denoted by N subscript), and the remainder is tradable (denoted by T subscript). Then:

$$p_t = \alpha p_{N,t} + (1-\alpha) p_{T,t} \quad (3)$$

By simple manipulation, one finds that the "relative price level" is given by (the inverse of the real exchange rate, conventionally defined):

$$r_t \equiv -(s_t - p_t + p_t^*) = -(s_t - p_{T,t} + p_{T,t}^*) + \alpha[p_{N,t} - p_{T,t}] + \alpha[p_{N,t}^* - p_{T,t}^*] \quad (4)$$

Rewriting, and indicating the first term in (parentheses), the intercountry price of tradables, as $r_{T,t}$ and the intercountry relative price of nontradables as $\omega_t \equiv [p_{N,t} - p_{T,t}] - [p_{N,t}^* - p_{T,t}^*]$, leads to the following rewriting of (4):

$$r_t = r_{T,t} + \alpha\omega_t \quad (4')$$

This expression indicates that the real price level can rise as changes occur in the relative price of traded goods between countries, or as the relative price of nontradables rises in one country, *relative to another*. In principle, economic factors can affect one or both.

Most models of the real exchange rate can be categorized according to which specific relative price serves as the object of focus. If the relative price of nontradables is key, then the resulting models – in a small country context – have been termed "dependent economy" (Salter, 1959, and Swan, 1960) or "Scandinavian" model. In the former case, demand side factors drive shifts in the relative price of nontradables. In the latter, productivity levels and the nominal exchange rate determine the nominal wage rate, and hence the price level and the relative price of nontradables. In this latter context, the real exchange rate is a function of productivity (Krueger, 1983: 157). Consequently, the two sets of models both focus on the relative nontradables price, but differ in their focus on the source of shifts in this relative price. Since the home economy is small relative to the world economy (hence, one is working with a one-country model), the tradable price is pinned down by the rest-of-the-world supply of traded goods. Hence, the "real exchange rate" in this case is ($p^N$-$p^T$).

By far dominant in this category are those that center on the relative price of nontradables. These include the specifications based on the approaches of Balassa (1964) and Samuelson (1964) that model the relative price of nontradables as a function of sectoral productivity differentials, including Hsieh (1982), Canzoneri, Cumby and Diba (1999), and Chinn (2000a). They also include those approaches that include demand side determinants of the relative price, such as that of DeGregorio, Giovannini and Wolf (1994). They observe that if consumption preferences are not homothetic and factors are not perfectly free to move intersectorally, changes in *per capita* income may result shifts in the relative price of nontradables.

This perspective provides the key rationale for the well-known positive cross-sectional relationship between relative price level and relative *per capita* income levels. We exploit this relationship to determine whether the Chinese currency is undervalued. Obviously, this approach is not novel; it has earlier been implemented by Frankel (2006) and Coudert and Couharde (2007). However, we will expand this approach along several dimensions. First, we augment the approach by incorporating the time series dimension.[4] Second, we consider both linear and quadratic income effects. Third, we explicitly characterize the uncertainty surrounding our determinations of currency misalignment. Fourth, we examine the stability of the relative price and relative *per capita* income relationship using a) subsamples of certain country groups and time periods, and b) control variables.

It is important to clarify the nature of "equilibrium" we are associating with our measure of the "normal" exchange rate level. Theoretically, the equilibrium exchange rate in the Balassa-Samuelson approach is the one that is consistent with both internal and external balances. In reality, however, the co-existence of internal and external balances is not guaranteed. Thus, the estimated exchange rate measure is properly interpreted as a long-run measure and is ill-suited (on its own) to analyzing short run phenomena.[5]

## 3. Data and Estimates

### *3.1 Data*

We rely upon price level and per capita income data, primarily derived from the PWT 8.1 (Feenstra, et al., 2013). The two most widely used sources in international macroeconomics are PWTs and the World Development Indicators (WDI), both of which are underpinned by the International Comparison Program (ICP). The ICP is a global statistical enterprise involving 199 countries. The goal of the ICP is to provide

[4] Coudert and Couharde (2007) implement the absolute PPP regression on a cross-section, while their panel estimation relies upon estimating the relationship between the relative price level to the relative tradables to nontradables price index.

[5] Frankel (2006) discusses whether one can speak of an "equilibrium exchange rate" when there is more than one sector to consider.

comparable data on the level of GDP and its components across countries. It specifically aims to provide estimates of PPP. The PWT8.1 and the most recent WDI are based on ICP 2011, which involved 177 participating economies (World Bank, 2015). However, PWT and WDI differ in numerous ways. Basically, WDI adheres closely to the methodology adopted by ICP. [6] The differences between the two sources suggest that users should keep cautious when trying to draw conclusions from either source (Ram and Ural, 2014). Consequently, we compare the results derived from PWT8.1 with the results from WDI and also PWT7.0 as robustness checks.

As noted by Feenstra et al. (2013), for over four decades, various incarnations of the PWTs have provided information regarding GDP and its components in a manner that can be compared over across countries, and over time. In principle, the price of the same bundle of goods and services is reported. Our basic dataset encompasses 158 countries over the 1970 – 2011 period.[7]

We estimate the Penn Effect relationship between the national price level (where the US level is normalized to 1) and the relative per capita income ratio (~~US to~~ country I to the US). Note that, under the ICP nomenclature, the national price level refers to a relative price, which is the inverse of the real exchange rate. We, for brevity, also call it price level. The regression equation can be represented by equation (5):

$$r_{i,t} = \beta_0 + \beta_1 y_{i,t} + u_{i,t} \tag{5}$$

[6] PWT uses the Geary-Khamis (GK) procedure to go from the basic heading level to consumption and investment and the GK procedure to combine these to total GDP, while WDI uses the GK procedure in most regions and the Iklé-Dikhanov-Balk (IDB) procedure in Africa (Feenstra, et al., 2013). GK procedure will tend to understate PPPs in poor countries and thus the prices it gets could be biased towards rich country prices (Deaton and Heston, 2010).

[7] The PWT 8.1 covers 167 countries over the 1950 – 2011 period. For our analysis, we exclude small countries and oil exporters with extreme values. We also take out countries that suffer from hyperinflation. Including the extreme observations in the regressions does not change the results, which is available upon request. Excluded countries include: Bahrain, Bermuda, Brunei, El Salvador, Equatorial Guinea, Kuwait, Qatar, Oman, Saudi Arabia, Slovenia in 1990, and Zimbabwe from 2008-2011.

where $r$ is the log national price level, and $y$ is per capita income relative to the United States. Because of missing observations, the panel is unbalanced. We investigate a variety of specifications, including allowing for fixed effects, nonlinearities, and additional covariates.

### *3.2 The Basic Bivariate Results*

The full sample scatter plot is shown in Figure 1. A quick glance confirms, even the data are quite dispersed, the positive relationship that has been repeatedly found in previous studies. We first estimate the real exchange rate—income relationship using a pooled time-series cross-section (OLS) regression. The results are reported in table 1. A pooled OLS regression forces the intercepts across countries to be the same, and assumes that the error term is distributed identically over the entire sample. Results of fixed effects and random effects will be discussed in the next section.

The pooled OLS linear regression for the full sample yields a 0.24 estimate for the elasticity of the price level with respect to per capita income, which is close to previous studies' estimate that ranges from 0.25 to 0.39 using WDI dataset (see Frankel 2006; Cheung et al., 2007). This simple linear model explains 29 percent of the overall variation of price level across countries and over time.

While there is a clear positive association between the price level and relative income, it's not so clear that it's a linear relationship. Adding a quadratic term to the regression yields:

$$r_{i,t} = \beta_0 + \beta_1 y_{i,t} + \beta_2 y_{i,t}^2 + u_{i,t}. \qquad (6)$$

The inclusion of the quadratic term improves the overall fit of the model, which captures 35 percent of the variations of price level. The coefficients for the linear term and the quadratic term are 0.62 and 0.10 respectively, and are both statistically significant. It suggests that relative price level falls initially and rises afterwards as per capita income increases. The corresponding scatter plot with a quadratic fit that provides a visual U-shaped fit with standard error bands is presented in Figure 2. This non-monotonic relationship between price level and per capita income echoes results in Hassan (forthcoming) and Subramanian and Kessler (2014).[8]

Following Hassan, we also conduct a formal test for the presence of a U shape using the test suggested by Lind and Mehlum (2009).[9] The results indicate that absence of a U-shaped relationship can be rejected at the 1 percent level. The extreme point is -3.25, which matches Bangladesh's relative per capita income in 2009. The results of the U-test are reported in Table 1.

This finding of a U-shaped relationship is interesting. One potential explanation, forwarded by Hassan (forthcoming), relies on the concept of structural transformation, à la Chenery and Syrquin (1975). Since poor countries' economies rely heavily on agriculture, which is nontradable at the early stage of development and occupies a large share of expenditure, the productivity growth of agriculture sector reduces the relative price of nontradables, and hence the overall price level.[10]

### *3.3 Robustness Tests: Comparing the Results from PWT 8.1 with PWT 7.0 and WDI*

[8] In both studies, the absolute level of per capita income is used instead of relative per capita income.

[9] They argue that the test for the exact necessary and sufficient conditions for a U shape requires the slope of the curve is negative at the start and positive at the end of the observed data range. In contrast, the statistical significance of the quadratic term is a weak criterion by which to judge the presence of a U-shaped relationship.

[10] Dekle and Ungor (2013), for example, offer an alternative perspective on the role of agriculture sector productivity in assessing the Penn effect.

The non-monotonic relationship between price level and per capita income has been little discussed in previous literature. That suggests checking the robustness of the coefficient on the quadratic term. In Table 2 we report the results derived from PWT 7.0 and WDI as robustness check. For a clearer comparison, we only maintain a common set of country-year observations in the regressions. Regressions with full sample do not change the primary results.

While the coefficient magnitudes vary across different datasets, the signs of coefficients are consistent, and most importantly, the quadratic terms and the presence of a U shape are statistically significant. The results further provide empirical evidence for the quadratic income effect; price levels decline and then rise as per capita income increases.[11]

### *3.4 Stratification by level of development*

In the following, for brevity we focus on the PWT 8.1 data set. There is reason to believe, given the results in for example Cheung et al. (2007), Fujii (2015), and Kravis and Lipsey (1987), that the developed and developing economies do not constitute a homogeneous grouping. That finding motivates investigation by stratifying the sample.

The elasticity of the price level with respect to *per capita* income may be different for developing countries and developed countries. For example, the manufacturing-services productivity differential is presumably more pronounced in developing countries, and as a consequence it would make sense that the Balassa-Samuelson effects are more pronounced in developing countries. Nevertheless, Cheung et al. (2007), Fujii (2015),

[11] The results are largely unchanged if the analyses are restricted to data associated with benchmark years. Hence, the findings are not driven by interpolated data. On the other hand, what is true is that cross-section estimates of linear and quadratic terms differ between benchmark years (1985, 1993, 2005, 2011), according to an F-test.

and Kravis and Lipsey (1987) indicate that the price elasticity exhibited by developed economies is larger than developing economies. Possibly, the price-income interactions are affected by different factors in these two country groups.[12]

We define developed countries as high-income countries listed by the World Bank in 1990, and fix countries' income status over time. We use 1990 as a reference date since it is roughly halfway through the full sample period.[13] Table 3 reports the results for developing and developed countries. Both the linear and quadratic specifications (columns 3~~5~~ and 4~~6~~) fit the data from developed countries better than data from developing countries, according to R-squared statistics.

In the absence of the quadratic term, the slope for developing countries is flatter than that of developed countries; that is, the price level is more sensitive to *per capita* income for developed than for developing countries. The result is consistent with the results in, for instance, Cheung et al. (2007), Fujii (2015), Kravis and Lipsey (1987), and Hassan (forthcoming). One possibility is that the negative relationship between price level and per capita income when income is low – as indicated in the U-shaped curve in Figure 2 - flattens the slope for developing countries. Scatter plots with linear fits for developing and developed countries are presented in figure 3 and figure 4. These figures affirm the relatively "flatness" result for developing countries.

An interesting result is that the quadratic term is statistically significant for both developing and developed countries, but with *different* signs. The data from developing countries display a U-shaped income effect while developed countries an inverted U-shaped one. Scatter plots with quadratic fits for developing and developed countries are presented in figures 5 and 6. The U-shaped income effect for the developing countries is

[12] The developed and developing economies can also display different patterns of exchange rate misalignment estimates (Cheung and Fujii, 2014a).

[13] As a robustness check, we test our results using income status classification in 2011. The results do not change substantively as a consequence of this alternative reference date.

visually more obvious than the inverted U-shaped one for developed countries. The formal test indicates that the presence of a U shape for the developing countries is significant at the 1 percent level while the inverted U-shape relationship for developed countries is significant at the 5 percent level.

The quadratic term implies that the elasticity of the price level with respect to *per capita* income depends on the level of GDP per capita. For example, compared to the 0.242 elasticity from the linear specification in Table 1, including the quadratic term decreases the 2011 implied elasticity for Nigeria to 0.109 but increases the implied elasticity for Korea to 0.539.

Since quadratic terms of the data from developed and developing countries have different signs, the nonlinearity effect has different implications for the elasticity of the price level with respect to per capita income for countries at different income levels.

In passing, we note that, in the presence of a quadratic term, the developing countries have a coefficient estimate of the linear income term larger than the developed countries; a reverse of the relative linear income effect displayed under columns (1) and (3). Also, one might think that in the full sample, a higher order relative income term would capture the attenuation of the Penn effect at top income levels. However, the inclusion of a cubic in relative income fails to exhibit statistical significance.

## 4 Alternative Specifications

### *4.1 Fixed effects*

One potential problem arising in dealing with cross-country data is unobserved heterogeneity. We employ fixed effects and random effects address this issue. The fixed effects approach assumes that the individual specific effects are correlated with the independent variables, and random effect approach assumes that the individual specific effects are uncorrelated with the independent variables. The Hausman test, however, rejects the random effects specification. Thus, for brevity Tables 4 and 5 only present results pertaining to fixed effects specifications; Table 4 is for the full country sample and Table 5 is for the income-stratified samples.[14]

The fixed effects within and between estimators provide discernably different income elasticity estimates. At the risk of over-simplification, the within estimator is driven by data variations over time within individual countries, and the between estimator by cross-country differences. Table 4 show that, for the sample including all the economies, estimates from the between specification are qualitatively similar to those in Table 1. The within specification, on the other hand, can yield different and even statistically insignificant estimates.

Apparently, it is the cross-country variation that underpins the observed linear and quadratic Penn effects. Alternatively, we interpret that these results indicate that the Penn effect is more pronounced between countries than within a country during different stages of development. In passing, we note that the between estimator is based on country-average-variables; the averaging process can mitigate country-specify measurement error.[15]

Table 5 shows that the inclusion of within and between features has different implications for data from developed and developing countries. Turning first to the developed economies, one finds that the inclusion of fixed within country effects has

[14] Another potential problem is serial correlation, as observations in this period within a country may be correlated with observations in the previous period. To address this problem, robust standard errors clustered by countries are used for inference.

[15] The implications of measurement errors for Penn regression and related misalignment estimation are illustrated by Cheung and Fujii (2014a). Further the averaging can alleviate the biases from serial correlation in the data which can affect the within estimator.

little impact on the results for the linear specification. However, the inclusion eliminates the effect of the relative income variables in the quadratic specification. The only statistically significant coefficient is that on the quadratic term, for the between estimator; moreover, the estimated coefficient has a negative sign that is the same as the one in Table 3.

For the developing economies, it is the between specification but not the within specification that gives linear and quadratic income effects similar to the corresponding ones in Table 3. That is, the U-shaped income effect is likely to be driven by differences across developing countries, and is carried over to the sample that has both developing and developed countries.

The specifications with both country and time fixed effects yield results that are qualitatively similar to those in Table 5; they are not reported for brevity, and are available upon request.

### *4.2 Controlling for Economic Factors*

Results in the previous subsection suggest that both the linear and quadratic Penn effects are likely to be a cross-country phenomenon.[16] Are these effects proxies for differences of country characteristics? Are there economic variables that determine what affects the price level? For instance, one commonly heard argument is that the corruption raises prices. Extensive capital control might impede trade and hence price arbitrage. Finally, commodity exporters – in particular oil exporters – might exhibit different price behavior.

We now investigate whether these particular aspects are of measurable importance in the determination of national real exchange rates, and if so, whether our conclusions

[16] Note that the so-called Penn effect is documented across cities within a country (Cheung and Fujii, 2014b).

regarding RMB misalignment are altered as a consequence. To this end, we consider the following augmented equations:

$$r_{i,t} = \beta_0 + \beta_1 y_{i,t} + \Gamma X_{i,t} + u_{i,t}, \qquad (7)$$

and

$$r_{i,t} = \beta_0 + \beta_1 y_{i,t} + \beta_2 y_{i,t}^2 + \Gamma X_{i,t} + u_{i,t}. \qquad (8)$$

The vector $X_{i,t}$ contains economic control variables, including an indicator variable for oil exporters, a financial openness measure, a corruption measure, and an interaction term between the last two. The indicator variable takes on a value of "1" for oil-exporters. The financial openness variable is the index of capital account openness developed by Chinn and Ito (2006). We use the International Country Risk Guide's (ICRG) Corruption Index as our measure of institutional development (where higher values of the index denote less corruption).

Table 6 presents results of estimating (7) and (8) for the developed and developing countries (columns 1-2, 5-6, respectively). Constrained by data availability, the sample sizes are smaller than those considered in Table 3. The inclusion of these additional explanatory variables does not qualitatively change linear and quadratic income effects reported in Table 3; for instance, a U-shaped income effect and an inverted U-shape are again found, respectively for developing and developed economies.

The astute reader will note some of the income effect estimates are quantitatively different from their counterparts in Table 3. However, it is hard to draw a precise comparison as the sample sizes considered are different in these two tables.

For the added variables, only two of our control variables are significant. Interestingly, being an oil-exporter increases the price level for developing countries but has the reverse effect on the price level for developed countries, controlling for other variables. At the same time, in the presence of relatively higher level of corruption, the price level is lower, controlling for other variables. The estimated corruption effect is different from the usual perception that corruption raises price level. Capital account openness and the interaction between corruption and openness do not have significant impact on price level in our results.

The presence of a U shape is less pronounced in the augmented models. The failure to detect a significant U-shaped relationship is partly due to the decrease of the sample size. Also, the position of the extreme point plays a role in the test for a U shape. The minimum for the developing countries is -5.08, but we have few observations to the left of the extremum. For developed countries the extreme point is 0.42, but the number of observations to the right of the extremum is very limited.

In sum, the nonlinear income effect is robust to these control variables, although the test for a U shape now fails to reject the null hypothesis.

One factor omitted from the previous analysis is some measure of intercountry transportation costs. In order to check whether the results are sensitive to this omission, we include remoteness, which is a trade weighted distance measure calculated for several years by UN DESA (2015). There is an additional increment to account for landlocked countries. Since we only have remoteness data for select years, we opt to fix on 2006, and convert the remoteness variable into a binary variable taking on a value of one when the value exceeds 0.75, which matches Nepal's remoteness value in 2006. The results are reported in columns 3 and 4 of Table 6. [17]

[17] Since no advanced economy is "remote" by the criterion we use, the advanced economy results are unchanged.

The estimated income parameters are largely unchanged, although now the relationship between income and the price level is monotonically increasing.[18] The other coefficients are qualitatively unaffected. However, in line with expectations, remote countries do exhibit substantially higher price levels – by 11%.

## 5 Estimating Exchange Rate Misalignment

Studies such as Cheung, Chinn, and Fujii (2010b) and Cheung and Fujii (2014a) show that very different exchange rate misalignment estimates can be obtained from different data vintages, and there is a considerable amount of uncertainty surrounding these estimates. Our exercise highlights another source of uncertainty – the specification uncertainty. Here we use the Chinese currency, the renminbi (RMB), to illustrate the point.

Table 7 reports the estimates of misalignment for the Chinese RMB using the Penn effect as a criterion. The linear and quadratic specifications ((equations (5) and (6)) for the full sample or the sample of developing economies are considered. [19] Misalignment estimates derived from PWT 7.0 and WDI datasets are included to highlight the implications of differences in data vintage and data source. Undervaluation (overvaluation) is indicated by a negative (positive) sign.

One commonality is that an undervaluation is indicated for 2005. That being said, there is considerable disagreement on the extent, even for the linear specification and the full sample: from -23.2% to -61.2% (Panel A). For the quadratic specification (Panel B), the misalignment estimates spread from -5.53% (WDI, developing) to -48.9% (PWT 8.1 developing). Interestingly, a quadratic specification typically generates a RMB

[18] The implied turning point is below the lowest income level.
[19] To retain comparability with other estimates, we rely on estimates from specifications omitting the remoteness variable.

*undervaluation* estimate that is smaller than one from a linear specification. It is true for all misalignment estimates presented in Panels A and B of Table 7.

Moving forward to 2009 the year the last data available for all three data sets, the diversity persists. For the linear specification applied to full samples, the estimates ranges from -27.7% to -5.83%. Using the developing sample, one estimate from the WDI suggests the RMB was overvalued by 7.12%. The quadratic specification gives a small level of RMB undervaluation – indeed, the WDI data indicate the RMB was overvalued by more than 10% by 2009 based on either full sample or data from developing countries.

In Figure 3, we show the trajectory of the Chinese RMB over the sample period (in red), against the scatterplot of developing economies from PWT 8.1. The RMB was more than one standard error below predicted in 2005, but already by 2010 the RMB was at predicted. Figure 5 that depicts the situation under the quadratic specification essentially tells a similar story - the RMB is about correctly valued by 2010. In other words, the same inferences are obtained using linear vs. quadratic.

2011 onward, the extent of RMB overvaluation is growing. The WDI data uniformly indicate overvaluation: from 6.97% (2011, full sample) to 27.1% (2014, sample of developing countries). A much milder overvaluation trend is provided by the PWT 8.1 dataset, though.

The possibility of a RMB overvaluation seldom garnered media attention until 2015. In May of that year, the International Monetary Fund stated that the RMB was at a level that is "no longer undervalued." [20] While the "no longer undervalued" assessment was shared by a long-time critic of China's foreign exchange policy (Cline, 2015), this conclusion was not in line with the U.S. Treasury Department, that reiterated its view

[20] International Monetary Fund (2015).

that the RMB was still substantially undervalued (U.S. Treasury, 2015); however, no such mention of undervaluation was made in the most recent report (U.S. Treasury, 2016).

Table 8 reports the results when the linear and quadratic models are augmented with control variables. Compared with the estimates in Table 7, the presence of control variables in most cases weakens the evidence of RMB undervaluation (or strengthens the evidence of RMB overvaluation). The evidence of RMB overvaluation in 2011 obtained from the PWT8.1 dataset does not differ substantially from those obtained from Table 7. However, the big differences arise when using the WDI dataset – the RMB was overvalued by more than 30% 2011 and thereafter. Again, quadratic specifications, compared with linear ones tend to yield larger estimates of RMB overvaluation.

From these results, we can infer that, in addition to data vintage and data source, the choice of a linear or a quadratic specification has implications for estimates of exchange rate misalignment. In the case of RMB, a quadratic specification tends to yield a lower level of undervaluation estimate or a larger overvaluation estimate.[21]

## 6 Conclusion

In this paper we document whether indeed the Penn effect is as robust as is typically conceived. Specifically we assess the presence of a nonlinear Penn effect. We focus on the recently available PWT 8.1 dataset, though results from alternative data sources are also discussed.

We find that the elasticity of the relative price level to per capita income is fairly consistently estimated, across data sets. However, there is some evidence that the

[21] The implications for misalignment assessment differs across countries. Cheung and Fujii (2014a), for example, shows misalignment estimates can be affected by a few economic variables and measurement related factors.

relationship is nonlinear; a quadratic term, implying a U-shaped relationship that is apparent from visual inspection of the data.

The nature of the nonlinearity displayed by the developed and developing economies differs. For the developed economies, the quadratic term implies an inverted U-shaped relationship between real exchange rate and income. The developing economies, on the other hand, display a U-shaped relationship. Additional analyses suggest that the nonlinearity is likely driven by variations across countries rather than by changes of data within a country, and is robust to the presence of selected economic covariates in the regression specification.

Our empirical results re-affirm the prevalence of the income and real exchange rate link, which is revealed in different versions of dataset. The documented nonlinear Penn effect; especially the differential nonlinear behaviors exhibited by developed and developing countries, nevertheless, warrants further theoretical and empirical investigations.

While the estimated elasticity is fairly consistently estimated across data sets, the implied degrees of misalignment do differ substantially. In addition to data vintage and data source, the choice of a linear or quadratic Penn effect can affect the assessment of exchange rate misalignment. We focus on the example of China as a means of highlighting these points.

As anticipated, the choice of specification has implications for estimating the degree of misalignment. In the case of China, a quadratic, instead of a linear, Penn effect specification tends to yield weaken (stronger) evidence of RMB undervaluation (overvaluation). Our estimates show that the RMB may have embarked on its overvaluation trend as early as 2011, if not 2009.

In general, our results suggest that particular care must be taken when making inferences regarding the degree of currency misalignment.

## Appendix 1: Data and Sources

The primary source for the data is PWT8.1. A secondary data source is PWT7.0, and the World Bank's Development Indicators. The price level is the price level ratio of PPP converted factor to market exchange rate (PPP/XR), in logs terms and relative to the U.S.

The basic sample drawn from PWT8.1 encompasses 150 countries over the 1970-2011 period. In our statistical analysis, we exclude small countries and oil exporters with extreme values, and countries that experience a bout of hyperinflation. Excluded countries include: Bahrain, Bermuda, Brunei, El Salvador, Equatorial Guinea, Kuwait, Qatar, Oman, Saudi Arabia, Slovenia in 1990, and Zimbabwe from 2008-2011.

The capital controls index is from Chinn and Ito (2006), and the (inverse) corruption index is drawn from the International Country Risk Guide (ICRG).

Remoteness is calculated for 2006, 2009, 2012, and 2015, and is drawn on UN Department of Economic and Social Affairs (2015). We use the 2006 values, and convert the continuous variable into a binary one by converting into a dummy variable the remoteness variable, taking on a value of 1 when remoteness exceeds 0.75, and 0 otherwise.

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**Table 1: Bivariate Relationship, for Full Sample**

Dependent Variable: Relative Price Level in logs and PPP terms

| VARIABLES | (1)<br>Model 1 | (2)<br>Model 2 |
|---|---|---|
| GDP per capita | 0.242*** | 0.620*** |
| | (0.00502) | (0.0145) |
| GDP per capita square | | 0.0953*** |
| | | (0.00375) |
| Constant | -0.0993*** | 0.152*** |
| | (0.00975) | (0.0109) |
| Observations | 6,152 | 6,152 |
| R-squared | 0.287 | 0.354 |
| Extreme point | | -3.25 |
| U test statistics | | 14.73*** |

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

**Table 2: Different Data Sets Using Common Sample**

Dependent Variable: Relative Price Level in logs and PPP terms

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| VARIABLES | PWT8.1 | PWT8.1 | WDI | WDI | PWT7.0 | PWT7.0 |
| GDP per capita | 0.290*** | 0.781*** | 0.305*** | 0.900*** | 0.184*** | 0.696*** |
| | (0.00680) | (0.0209) | (0.00711) | (0.0213) | (0.00720) | (0.0209) |
| GDP per capita square | | 0.121*** | | 0.153*** | | 0.121*** |
| | | (0.00521) | | (0.00502) | | (0.00542) |
| Constant | -0.0952*** | 0.224*** | -0.254*** | 0.103*** | -0.234*** | 0.0974*** |
| | (0.0138) | (0.0161) | (0.0141) | (0.0181) | (0.0139) | (0.0139) |
| Observations | 2,923 | 2,923 | 2,923 | 2,923 | 2,923 | 2,923 |
| R-squared | 0.429 | 0.542 | 0.436 | 0.602 | 0.248 | 0.426 |
| Extreme point | | -3.22 | | -2.95 | -2.87 | |
| U test statistics | | 13.81*** | | 19.58*** | 13.60*** | |

Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

**Table 3: Stratification by Income Levels**

Dependent Variable: Relative Price Level in logs and PPP terms

| VARIABLES | (1)<br>developing | (2)<br>developing | (3)<br>developed | (4)<br>developed |
|---|---|---|---|---|
| GDP per capita | 0.124*** | 0.385*** | 0.416*** | 0.146*** |
| | (0.00691) | (0.0313) | (0.0285) | (0.0563) |
| GDP per capita square | | 0.0534*** | | -0.320*** |
| | | (0.00650) | | (0.0565) |
| Constant | -0.421*** | -0.148*** | 0.158*** | 0.130*** |
| | (0.0162) | (0.0337) | (0.0130) | (0.0140) |
| Observations | 4,934 | 4,934 | 1,218 | 1,218 |
| R-squared | 0.062 | 0.074 | 0.191 | 0.226 |
| Extreme point | | -3.60 | | 0.229 |
| U test statistics | | 4.61*** | | 2.14** |

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

**Table 4: Fixed Effects, Double Fixed Effects, and Random Effects, for Full Sample**

Dependent Variable: Relative Price Level in logs and PPP terms

| VARIABLES | Fixed effects (within) | Fixed effects (between) | Fixed effects (within) | Fixed effects (between) |
|---|---|---|---|---|
| GDP per capita | 0.0939* | 0.249*** | -0.00817 | 0.788*** |
| | (0.0515) | (0.0259) | (0.0961) | (0.0847) |
| GDP per capita square | | | -0.0205 | 0.138*** |
| | | | (0.0210) | (0.0209) |
| Constant | 0.386*** | -0.118** | 0.481*** | 0.234*** |
| | (0.100) | (0.0573) | (0.108) | (0.0736) |
| Observations | 6,152 | 6,152 | 6,152 | 6,152 |
| R-squared | 0.010 | 0.374 | 0.012 | 0.511 |
| Number of countries | 158 | 158 | 158 | 158 |
| Extreme point | | | -0.200 | -2.86 |
| U test statistics | | | 0.29 | 4.74*** |

Robust standard errors in parentheses, cluster
*** p<0.01, ** p<0.05, * p<0.1

**Table 5: Fixed effects, Stratified by Income Levels**

Dependent Variable: Relative Price Level in logs and PPP terms

| VARIABLES | (1)<br>developing<br>(within) | (3)<br>developing<br>(between) | (2)<br>developing<br>(within) | (4)<br>developing<br>(between) | (3)<br>developed<br>(within) | (7)<br>developed<br>(between) | (4)<br>developed<br>(within) | (8)<br>developed<br>(between) |
|---|---|---|---|---|---|---|---|---|
| GDP per capita | 0.0893 | 0.117*** | -0.0972 | 0.642*** | 0.147** | 0.619*** | -0.0131 | -0.0278 |
| | (0.0555) | (0.0351) | (0.148) | (0.187) | (0.0627) | (0.149) | (0.154) | (0.247) |
| GDP per capita square | | | -0.0350 | 0.111*** | | | -0.159 | -0.894*** |
| | | | (0.0289) | (0.0386) | | | (0.105) | (0.290) |
| Constant | -0.503*** | -0.469*** | -0.718*** | 0.0601 | 0.0608** | 0.231*** | 0.0376 | 0.191*** |
| | (0.130) | (0.0857) | (0.188) | (0.203) | (0.0226) | (0.0630) | (0.0338) | (0.0565) |
| Observations | 4,934 | 4,934 | 4,934 | 4,934 | 1,218 | 1,218 | 1,218 | 1,218 |
| R-squared | 0.009 | 0.081 | 0.013 | 0.137 | 0.027 | 0.390 | 0.039 | 0.554 |
| Number of countries | 129 | 129 | 129 | 129 | 29 | 29 | 29 | 29 |
| Extreme point | | | -1.39 | -2.91 | | | -0.041 | -0.016 |
| U test statistics | | | 0.78 | 2.31** | | | 0.76 | 1.98** |

Robust standard errors in parentheses, cluster
*** p<0.01, ** p<0.05, * p<0.1

**Table 6: Augmented Specifications**

Dependent Variable: Relative Price Level in logs and PPP terms

| VARIABLES | (1) developing | (2) developing | (3) developing | (4) developing | (5) developed | (6) developed |
|---|---|---|---|---|---|---|
| GDP per capita | 0.182*** | 0.347*** | 0.197*** | 0.340*** | 0.303*** | 0.167** |
| | (0.0145) | (0.0668) | (0.0155) | (0.0675) | (0.0485) | (0.0670) |
| GDP per capita square | | 0.0341** | | 0.0298** | | -0.199*** |
| | | (0.0138) | | (0.0140) | | (0.0762) |
| Capital account openness | -0.00948 | -0.0103 | -0.00846 | -0.00925 | 0.00975 | 0.0139 |
| | (0.0170) | (0.0168) | (0.0168) | (0.0166) | (0.0314) | (0.0316) |
| Oil-exporters | 0.179*** | 0.174*** | 0.177*** | 0.172*** | -0.164*** | -0.186*** |
| | (0.0495) | (0.0495) | (0.0494) | (0.0496) | (0.0441) | (0.0431) |
| Corruption | 0.0305*** | 0.0284*** | 0.0244*** | 0.0228** | 0.0406*** | 0.0262** |
| | (0.00907) | (0.00903) | (0.00897) | (0.00892) | (0.0102) | (0.0112) |
| Interaction term | 0.00773 | 0.00742 | 0.00750 | 0.00723 | -0.000861 | -0.00144 |
| | (0.00517) | (0.00516) | (0.00512) | (0.00511) | (0.00637) | (0.00639) |
| Remoteness | | | 0.110*** | 0.106*** | | |
| | | | (0.0300) | (0.0304) | | |
| Constant | -0.380*** | -0.204*** | -0.357*** | -0.204** | 0.00906 | 0.0707 |
| | (0.0445) | (0.0789) | (0.0455) | (0.0801) | (0.0483) | (0.0550) |
| Observations | 1,225 | 1,225 | 1,225 | 1,225 | 451 | 451 |
| R-squared | 0.144 | 0.147 | 0.154 | 0.156 | 0.305 | 0.327 |
| Extreme point | | -5.08 | | -5.71 | | 0.42 |
| U test statistics | | 0.14 | | n.a. | | 0.60 |

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

**Table 7: Chinese RMB Misalignment**

**Panel A: Linear Specifications**

| | PWT7.0 full | PWT7.0 developing | PWT8.1 full | PWT8.1 developing | WDI full | WDI developing |
|---|---|---|---|---|---|---|
| 2005 | -43.4% (0.87) | -35.0% (0.69) | -61.2% (1.41) | -52.4% (1.18) | -23.2% (0.54) | -16.0% (0.39) |
| 2009 | -19.8% (0.40) | -6.25% (0.12) | -27.7% (0.64) | -15.0% (0.34) | -5.83% (0.13) | 7.12% (0.17) |
| 2011 | | | -10.9% (0.25) | 2.81% (0.06) | 6.97% (0.16) | 22.0% (0.54) |
| 2014 | | | | | 8.66% (0.20) | 25.8% (0.63) |

Misalignment in log terms. Standard errors of the predictions in parentheses

**Panel B: Quadratic Specifications**

| | PWT7.0 full | PWT7.0 developing | PWT8.1 full | PWT8.1 developing | WDI full | WDI developing |
|---|---|---|---|---|---|---|
| 2005 | -30.6% (0.64) | -31.5% (0.63) | -48.7% (1.17) | -48.9% (1.11) | -5.60% (0.14) | -5.53% (0.14) |
| 2009 | -7.49% (0.16) | -4.44% (0.09) | -16.2% (0.39) | -13.7% (0.31) | 11.7% (0.30) | 13.8% (0.35) |
| 2011 | | | -0.01% (0.00) | 3.37% (0.08) | 23.3% (0.60) | 26.2% (0.67) |
| 2014 | | | | | 23.1% (0.59) | 27.1% (0.68) |

Misalignment in log terms. Standard errors of the predictions in parentheses

**Table 8: Chinese RMB Misalignment in the presence of control variables**

**Panel A: Linear Specifications with Control Variables**

| | PWT7.0 full | PWT7.0 developing | PWT8.1 full | PWT8.1 developing | WDI full | WDI developing |
|---|---|---|---|---|---|---|
| 2005 | -39.4% (0.86) | -36.6% (0.75) | -54.8% (1.38) | -50.4% (1.18) | -7.62% (0.22) | -7.07% (0.20) |
| 2009 | -16.4% (0.36) | -4.44% (0.24) | -19.9% (0.50) | -13.8% (0.32) | 13.5% (0.39) | 16.7% (0.49) |
| 2011 | | | -3.26% (0.08) | 3.54% (0.08) | 25.9% (0.75) | 30.5% (0.90) |
| 2014 | | | | | 27.2% (0.79) | 33.3% (0.99) |

Misalignment in log terms. Standard errors of the predictions in parentheses

**Panel B: Quadratic Specifications with Control Variables**

| | PWT7.0 full | PWT7.0 developing | PWT8.1 full | PWT8.1 developing | WDI full | WDI developing |
|---|---|---|---|---|---|---|
| 2005 | -34.4% (0.76) | -39.3% (0.81) | -48.7% (1.26) | -48.5% (1.13) | 3.08% (0.11) | -6.03% (0.20) |
| 2009 | -12.1% (0.27) | -12.6% (0.26) | -15.1% (0.39) | -13.3% (0.31) | 22.1% (0.75) | 23.3% (0.77) |
| 2011 | | | 1.09% (0.03) | 3.49% (0.08) | 33.1% (1.13) | 33.5% (1.12) |
| 2014 | | | | | 32.4% (1.11) | 31.9% (1.06) |

Misalignment in log terms. Standard errors of the predictions in parentheses

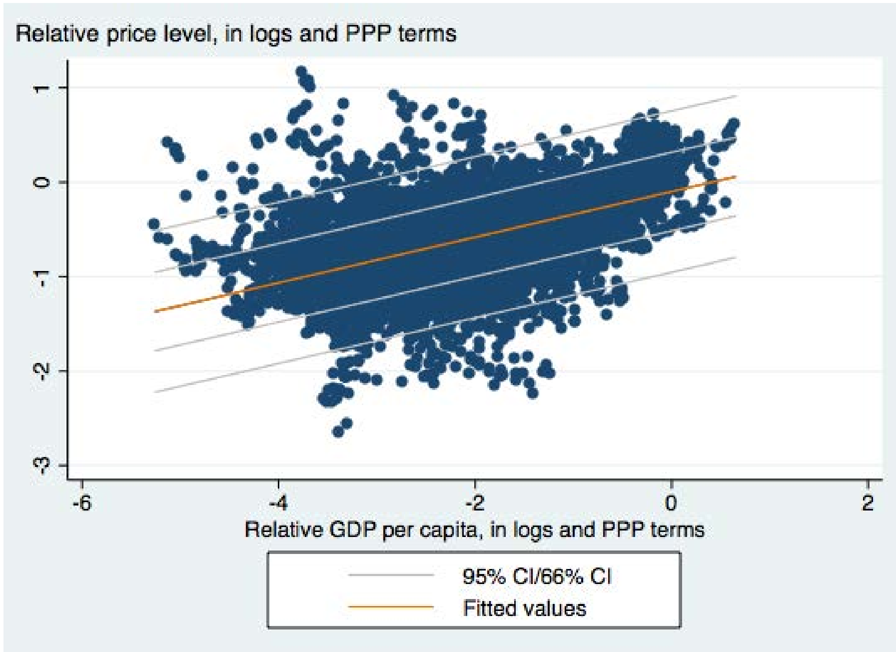


Figure 1 Scatter plot of full sample and linear fit

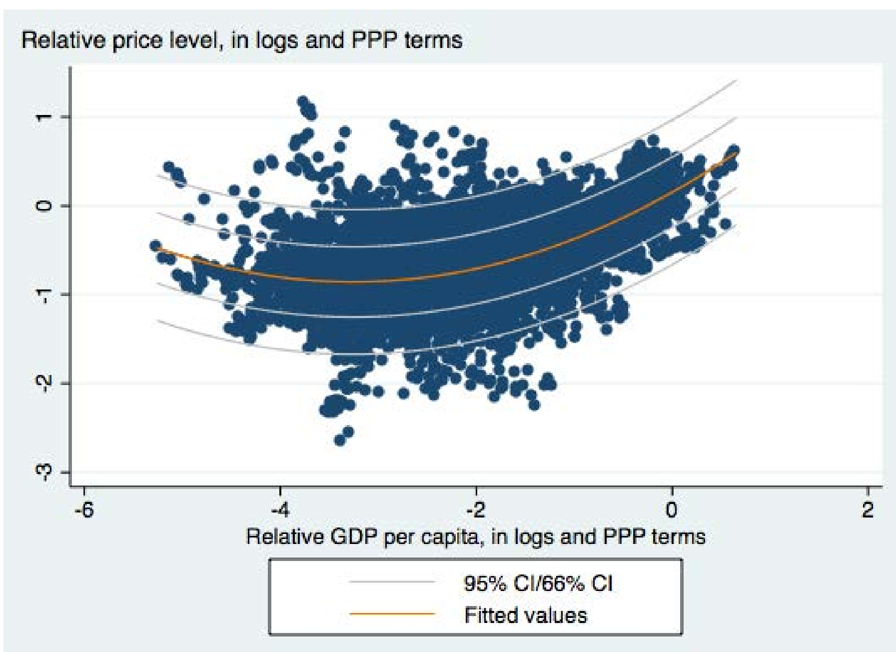


Figure 2 Scatter plot of full sample and quadratic fit

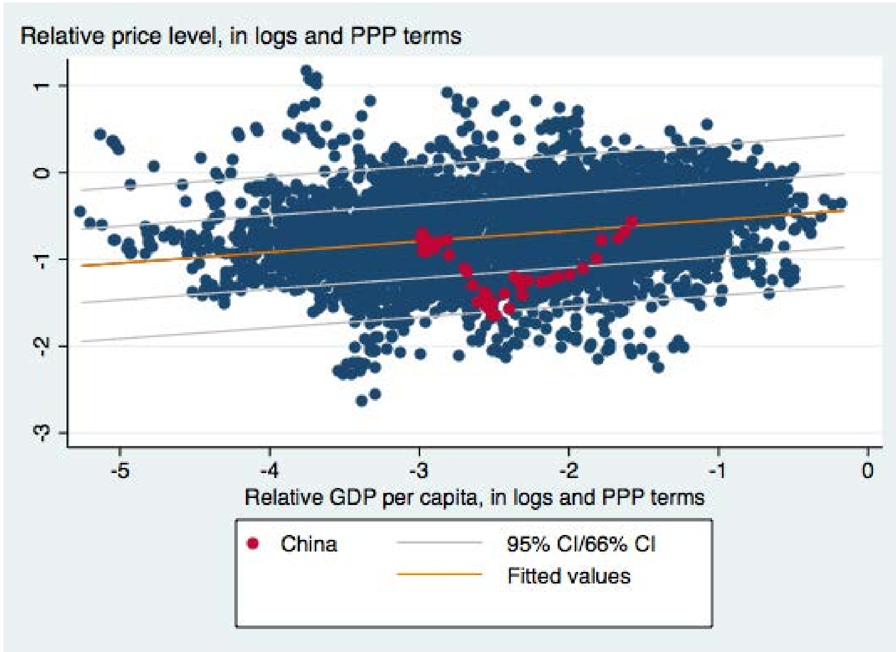


Figure 3 Linear fit for developing countries

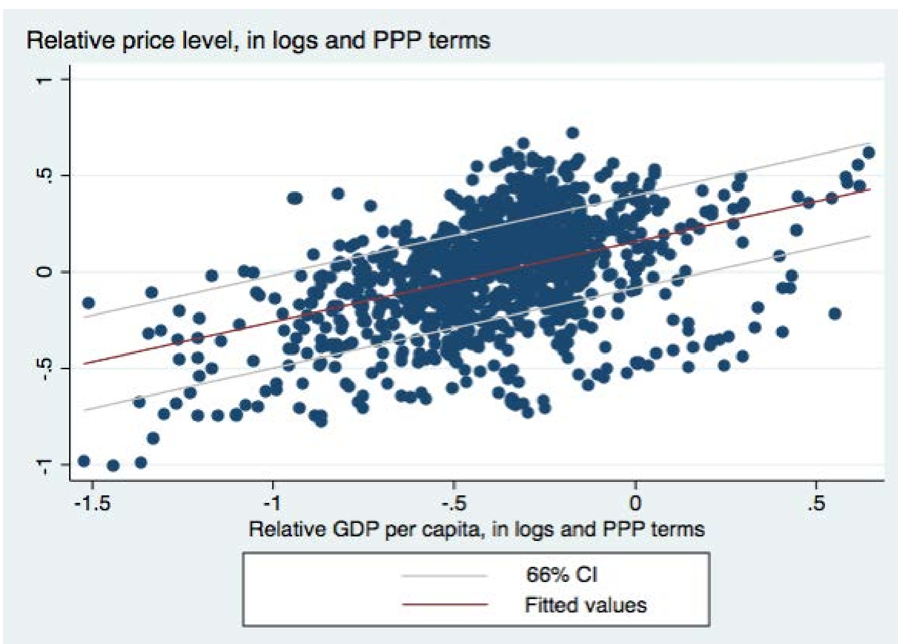


Figure 4 Linear fit for developed countries

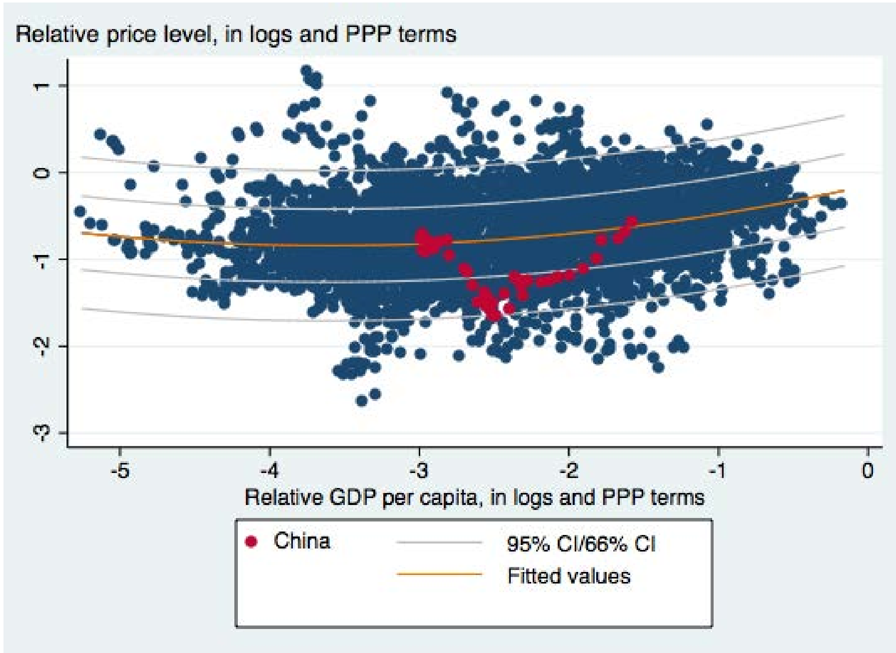


Figure 5 Quadratic fit for developing countries

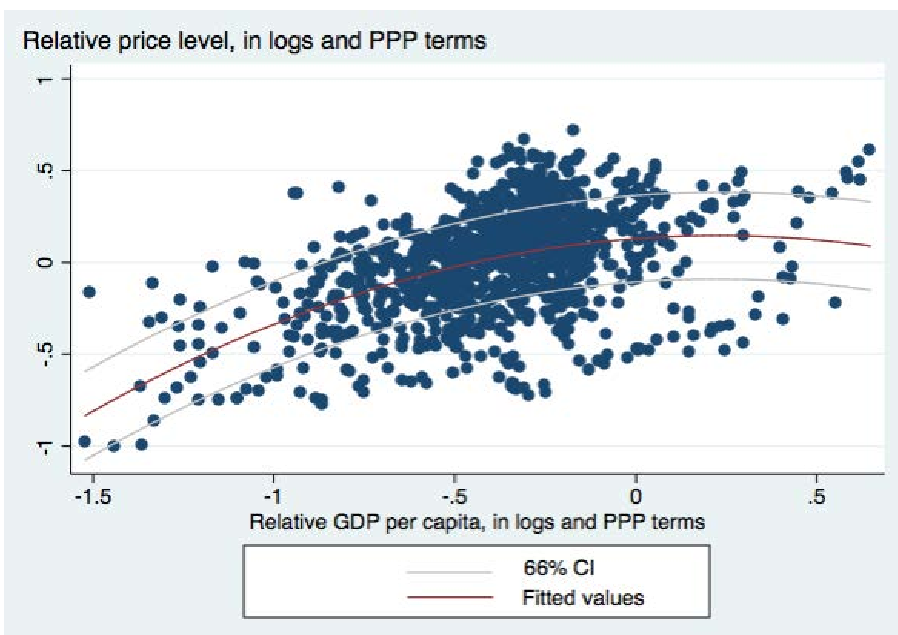


Figure 6 Quadratic fit for developed countries