

Estimating currency misalignment using the Penn effect: It is not as simple as it looks

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Abstract

We investigate the robustness of the Penn effect—the finding that the price level is higher in countries with a higher per capita income—over different samples, measures, and specifications. Testing for the Penn effect has been hampered by the imprecision of the price measures, so that use of different versions of the data set can lead to substantially different results. We find that the price level-income elasticity is fairly consistently estimated across data sets. However, there is some evidence that the relationship is non-linear. For developed economies, the quadratic term implies an inverted U-shaped relationship. Developing economies, on the other hand, display a U-shaped relationship. Estimates of misalignment differ, depending on the choice of specification and data sets. It appears that the Renminbi (RMB) was fairly valued by 2011. In contrast, the RMB's value was undervalued in 2005, and overvalued in 2014.

1 | INTRODUCTION

The issue of currency misalignment is a perennial one. As long as countries strive to reallocate aggregate demand in their own favour, 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 (PPP) 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 non-tradable 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, over different samples, measures, and specifications. 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, some recent work has suggested the presence of a non-linear Penn effect, namely a quadratic link between income and real exchange rate.

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 non-linear; a statistically significant quadratic term, implying a U-shaped relationship, is estimated.

The nature of the non-linearity displayed by developed and developing economies differs. For developed economies, the quadratic term implies an inverted U-shaped relationship between real exchange rate and income. Developing economies, on the other hand, display a U-shaped relationship. Additional analyses suggest that the non-linearity 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.

In the case of China, the inclusion of a significant quadratic term, unsurprisingly, has implications for the magnitude of the estimated degree of misalignment, particularly when the full country sample is used in determining the exchange rate norm. Estimates of misalignment for other currencies will differ as well, to varying degrees, depending on the choice of linear versus quadratic specification. The choice of data sets also has a material impact on the estimates.

In terms of the Chinese currency, it appears that the Renminbi (RMB) was fairly valued by 2011. In contrast, the RMB's value was undervalued in 2005, and overvalued in 2014 if one uses a one standard error threshold; not so if one uses a 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, Chinn, & Fujii, 2007).

Looking forward, according to our estimates, as long as Chinese per capita growth exceeds that of the United States, then the long-run equilibrium value of the RMB will continue to rise. The pace of increase is about 0.25 for each 1% increase in relative per capita income, holding constant other factors such as financial openness and levels of corruption.

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 PPP or cost competitiveness calculation, the modelling of deviations from absolute PPP,³ a composite model incorporating several channels of effects (sometimes called behavioural equilibrium exchange rate models), or flow equilibrium models. These alternative approaches are reviewed in, for example, Cheung et al. (2007), and Cheung, Chinn, and Fujii (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.⁴

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):

$$p_{i,t} = s_t + p_{i,t}^* \quad (1)$$

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 PPP condition:

$$p_t = s_t + p_t^* \quad (2)$$

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

The 'price level' variable in the Penn World Tables (PWTs) (Summers & Heston, 1991), and other PPP 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 non-tradable (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 non-tradables 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 non-tradables 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 non-tradables is key, then the resulting models—in a small country context—have been termed 'dependent economy' (Salter, 1959; Swan, 1960) or 'Scandinavian' model. In the former case, demand side factors drive shifts in the relative price of non-tradables. 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 non-tradables. In this latter context, the real exchange rate is a function of productivity (Krueger, 1983, p. 157). Consequently, the two sets of



models both focus on the relative non-tradables 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, in this literature, the 'real exchange rate' is $(p_N - p_T)$.⁵

By far dominant in this category are those that centre on the relative price of non-tradables. These include the specifications based on the approaches of Balassa (1964) and Samuelson (1964) that model the relative price of non-tradables as a function of sectoral productivity differentials, including Hsieh (1982), Canzoneri, Cumby, and Diba (1999), and Chinn (2000). They also include those approaches that include demand side determinants of the relative price, such as that of De Gregorio, 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 in shifts in the relative price of non-tradables.

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.⁶ 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 which allows for intersectoral factor mobility is the one that is consistent with internal balance and external equilibrium. In reality, however, the coexistence of internal and external equilibria 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 analysing short-run phenomena.⁷

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, Inklaar, & Timmer, 2015). 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 comparable data on the level of GDP and its components across countries. It specifically aims to provide estimates of PPPs, which are internationally comparable price measures in local currencies. The PWT 8.1 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 the ICP.⁸ The differences between the two sources suggest that users should be cautious when drawing general conclusions from either source (Ram & Ural, 2014). Consequently, we compare the results derived from PWT 8.1 with the results from WDI and also PWT 7.0 as robustness checks.

As noted by Feenstra et al. (2015), for over four decades, various incarnations of the PWTs have provided information regarding GDP and its components in a manner that can be compared across

countries, and over time. In principle, the price of the same bundle of goods and services is reported. Our basic data set encompasses 158 countries over the 1970–2011 period.⁹

We estimate the Penn effect relationship between the national price level (where the U.S. level is normalized to 1) and the relative per capita income ratio (country i to the United States). Note that, under the ICP nomenclature, the national price level refers to a relative price, which is the inverse of the real exchange rate and is based on PPPs obtained from ICP surveys. For brevity, we also call it price level. The regression equation is represented by equation (5):

$$r_{i,t} = \beta_0 + \beta_1 y_{i,t} + u_{i,t} \quad (5)$$

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, non-linearities, and additional covariates.

3.2 | The basic bivariate results

The full sample scatter plot is shown in Figure 1. A quick glance confirms, even though 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' estimates that range from 0.25 to 0.39 using the WDI data set (see Frankel, 2006; Cheung et al., 2007). This simple linear model explains 29% 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 is not so clear that it is a linear relationship. Adding a quadratic term to the regression yields:

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

The inclusion of the quadratic term improves the overall fit of the model, which captures 35% 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 (2016) and Kessler and Subramanian (2014).¹⁰

Following Hassan, we also conduct a formal test for the presence of a U shape using the test suggested by Lind and Mehlum (2009).¹¹ The results indicate that absence of a U-shaped relationship can be rejected at the 1% 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 (2016), relies on the concept of structural transformation, à la Chenery, Syrquin, and Elkington (1975). Since poor countries' economies rely heavily on agriculture, which is non-tradable at the early

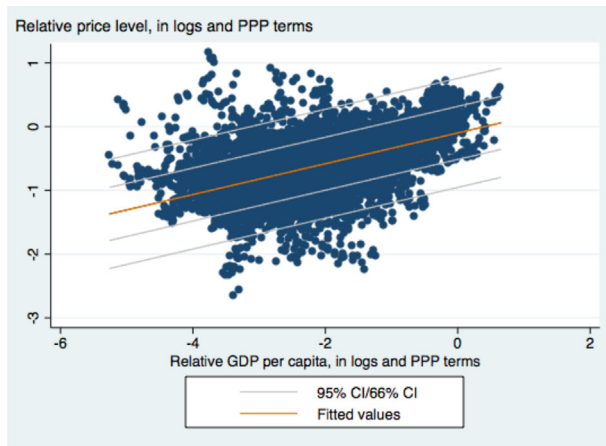


FIGURE 1 Scatter plot of full sample and linear fit

stage of development and occupies a large share of expenditure, the productivity growth of the agriculture sector reduces the relative price of non-tradables, and hence the overall price level.¹²

3.3 | Robustness tests: Comparing the results from PWT 8.1 with PWT 7.0 and WDI

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 a robustness check. For a clearer comparison, we only maintain a common set of country-year observations in the regressions. Regressions with the full sample do not change the primary results.

While the coefficient magnitudes vary across different data sets, the signs of coefficients are consistent, and most importantly, the quadratic terms and the presence of a U shape are statistically significant. The results provide further empirical evidence for the quadratic income effect; price levels decline and then rise as per capita income increases.¹³

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 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 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), and Kravis and Lipsey (1987) indicate that the price elasticity exhibited by developed economies is larger than that exhibited by developing economies. Possibly, the price–income interactions are affected by different factors in these two country groups.¹⁴

TABLE 1 Bivariate relationship, for full sample

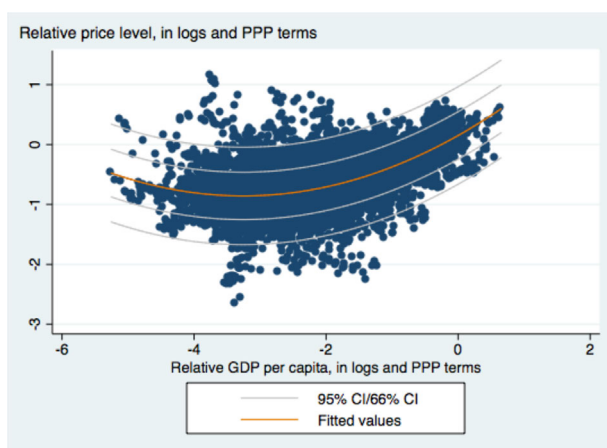
Variables	(1) Model 1	(2) Model 2
GDP per capita	0.242*** (0.00502)	0.620*** (0.0145)
GDP per capita squared		0.0953*** (0.00375)
Constant	-0.0993*** (0.00975)	0.152*** (0.0109)
Observations	6,152	6,152
R-squared	0.287	0.354
Extreme point		-3.25
U test statistics		14.73***

Robust standard errors in parentheses. Dependent variable: Relative price level in logs and PPP terms.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

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.¹⁵ Table 3 reports the results for developing and developed countries. Both the linear and quadratic specifications (columns 3 and 4) 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 (2016). 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 Figures 3 and 4. These figures affirm the relatively 'flatness' result for developing countries.

**FIGURE 2** Scatter plot of full sample and quadratic fit

**TABLE 2** Different data sets using common sample

Variables	(1) PWT 8.1	(2) PWT 8.1	(3) WDI	(4) WDI	(5) PWT 7.0	(6) PWT 7.0
GDP per capita	0.290*** (0.00680)	0.781*** (0.0209)	0.305*** (0.00711)	0.900*** (0.0213)	0.184*** (0.00720)	0.696*** (0.0209)
GDP per capita squared		0.121*** (0.00521)		0.153*** (0.00502)		0.121*** (0.00542)
Constant	-0.0952*** (0.0138)	0.224*** (0.0161)	-0.254*** (0.0141)	0.103*** (0.0181)	-0.234*** (0.0139)	0.0974*** (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. Dependent variable: Relative price level in logs and PPP terms.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

TABLE 3 Stratification by income levels

Variables	(1) Developing	(2) Developing	(3) Developed	(4) Developed
GDP per capita	0.124*** (0.00691)	0.385*** (0.0313)	0.416*** (0.0285)	0.146*** (0.0563)
GDP per capita squared		0.0534*** (0.00650)		-0.320*** (0.0565)
Constant	-0.421*** (0.0162)	-0.148*** (0.0337)	0.158*** (0.0130)	0.130*** (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. Dependent variable: Relative price level in logs and PPP terms.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

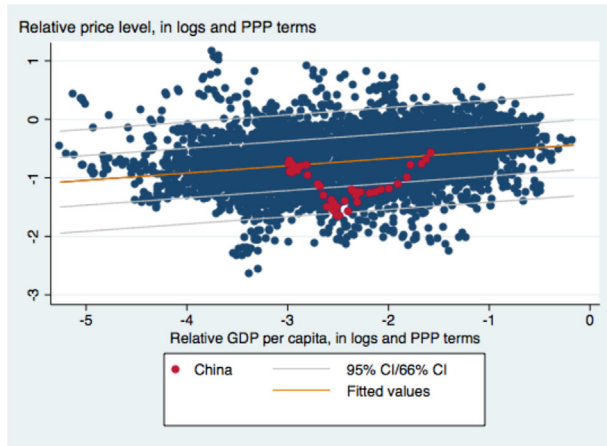


FIGURE 3 Linear fit for developing countries

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 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% level while the inverted U-shape relationship for developed countries is significant at the 5% 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 non-linearity effect has different implications for the elasticity of the price level with respect to per capita income for countries at different income levels.

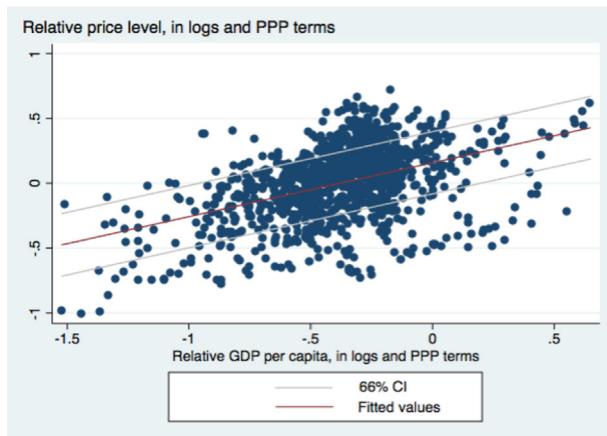


FIGURE 4 Linear fit for developed countries

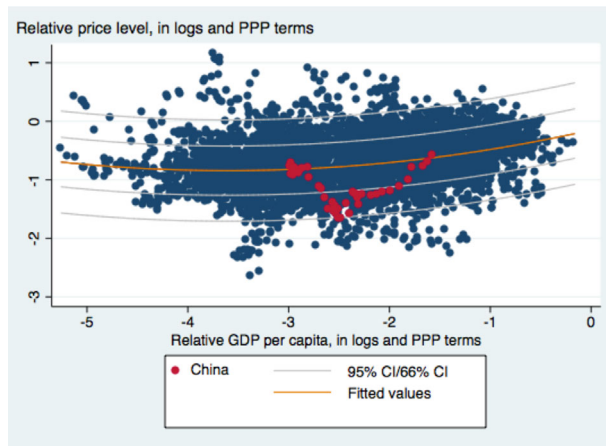


FIGURE 5 Quadratic fit for developing countries

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 to address this issue. The fixed effects approach assumes that the individual specific effects are correlated with the independent variables, and the random effects

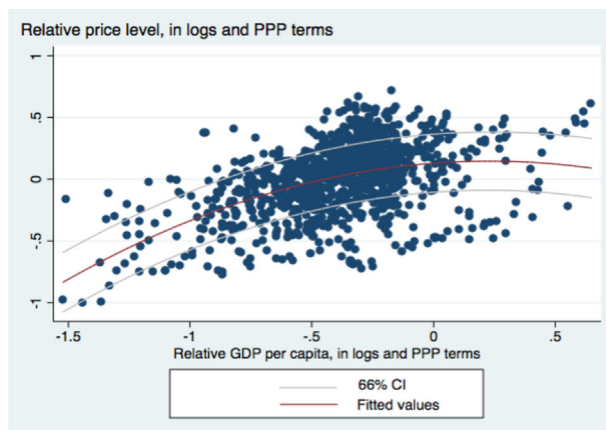


FIGURE 6 Quadratic fit for developed countries

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.¹⁶

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 shows that, for the sample including all the economies, estimates from the between specifications 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-specific measurement error.¹⁷

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 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 estimators; 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, but are available upon request.

TABLE 4 Fixed effects, double fixed effects, and random effects, for full sample

Variables	Fixed effects (within)	Fixed effects (between)	Fixed effects (within)	Fixed effects (between)
GDP per capita	0.0939* (0.0515)	0.249*** (0.0259)	-0.00817(0.0961)	0.788*** (0.0847)
GDP per capita squared			-0.0205 (0.0210)	0.138*** (0.0209)
Constant	0.386*** (0.100)	-0.118** (0.0573)	0.481*** (0.108)	0.234*** (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. Dependent variable: Relative price level in logs and PPP terms.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.


TABLE 5 Fixed effects, stratified by income levels

Variables	(1) Developing (within)	(3) Developing (between)	(2) Developing (within)	(4) Developing (between)	(3) Developed (within)	(7) Developed (between)	(4) Developed (within)	(8) Developed (between)
GDP per capita	0.0893 (0.0555)	0.117*** (0.0351)	-0.0972 (0.148)	0.642*** (0.187)	0.147** (0.0627)	0.619*** (0.149)	-0.0131 (0.154)	-0.0278 (0.247)
GDP per capita squared			-0.0350 (0.0289)	0.111*** (0.0386)			-0.159 (0.105)	-0.894*** (0.290)
Constant	-0.503*** (0.130)	-0.469*** (0.0857)	-0.718*** (0.188)	0.0601 (0.203)	0.0608** (0.0226)	0.231*** (0.0630)	0.0376 (0.0338)	0.191*** (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. Dependent variable: Relative price level in logs and PPP terms.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

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.¹⁸ 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 corruption raises prices. Extensive capital control might impede trade and hence price arbitrage. Finally, commodity exporters—in particular oil exporters—might exhibit different price behaviour.

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

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

and

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

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 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 levels of corruption, the price level is generally higher, in line with priors. 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 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.



TABLE 6 Augmented specifications

Variables	(1) Developing	(2) Developing	(3) Developing	(4) Developing	(5) Developed	(6) Developed
GDP per capita	0.182*** (0.0145)	0.347*** (0.0668)	0.197*** (0.0155)	0.340*** (0.0675)	0.303*** (0.0485)	0.167** (0.0670)
GDP per capita squared		0.0341** (0.0138)		0.0298** (0.0140)		-0.199*** (0.0762)
Capital account openness	-0.00948 (0.0170)	-0.0103 (0.0168)	-0.00846 (0.0168)	-0.00925 (0.0166)	0.00975 (0.0314)	0.0139 (0.0316)
Oil exporters	0.179*** (0.0495)	0.174*** (0.0495)	0.177*** (0.0494)	0.172*** (0.0496)	-0.164*** (0.0441)	-0.186*** (0.0431)
Corruption	0.0305*** (0.00907)	0.0284*** (0.00903)	0.0244*** (0.00897)	0.0228** (0.00892)	0.0406*** (0.0102)	0.0262** (0.0112)
Interaction term	0.00773 (0.00517)	0.00742 (0.00516)	0.00750 (0.00512)	0.00723 (0.00511)	-0.000861 (0.00637)	-0.00144 (0.00639)
Remoteness			0.110*** (0.0300)	0.106*** (0.0304)		
Constant	-0.380*** (0.0445)	-0.204*** (0.0789)	-0.357*** (0.0455)	-0.204** (0.0801)	0.00906 (0.0483)	0.0707 (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. Dependent variable: Relative price level in logs and PPP terms.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

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 the United Nations Department of Economic and Social Affairs (2015). There is an additional increment to account for landlocked countries.¹⁹ 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 a value of 1 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.^{20, 21}

The estimated income parameters are largely unchanged, although now the relationship between income and the price level is monotonically increasing over the sample, as the implied turning point is below the lowest income level. The other coefficients are qualitatively unaffected. However, in line with expectations, remote countries do exhibit substantially higher price levels—by 11%.

Some of the additional variables in the augmented specification could arguably be considered influenced by the price level, including most prominently financial openness, and perhaps even corruption. In order to investigate the sensitivity of the results to two-way causality, we implement two-stage least squares, using as instrumental variables once lagged right-hand side variables. The coefficient estimates on income and income squared do not change appreciably. In addition, those coefficients that are statistically significant in the OLS specification remain so when using two-stage least squares. Hence, we conclude that the associations we find are not driven by endogeneity.²²

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 RMB, to illustrate the point.

Following common practice, the empirical ‘equilibrium’ real exchange rate is given by the fitted dependent variable $\hat{r}_{i,t}$, and the estimated degree of misalignment by the estimated residual $\hat{u}_{i,t}$. That is, we implicitly assume the Penn effect, and we further assume that, conditional on income and other control variables, real exchange rates relative to the United States may be overvalued or undervalued but they are on average at equilibrium levels.

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.²³ Misalignment estimates derived from PWT 7.0 and WDI data sets 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 an RMB *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 are available for all three data sets, the diversity persists. For the linear specification applied to full samples, the estimates range from -27.7% to -5.83% . Using the developing sample, one estimate from the WDI suggests RMB was overvalued by

TABLE 7 Chinese RMB misalignment

	PWT 7.0 full	PWT 7.0 developing	PWT 8.1 full	PWT 8.1 developing	WDI full	WDI developing
Panel A: Linear specifications						
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)
Panel B: Quadratic specifications						
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.

7.12%. The quadratic specification gives a small level of RMB undervaluation—indeed, the WDI data indicate 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. RMB was more than one standard error below predicted in 2005, but already by 2010 it was at predicted level. Figure 5, which depicts the situation under the quadratic specification, essentially tells a similar story—RMB is about correctly valued by 2010. In other words, the same inferences are obtained using linear versus quadratic specifications.

From 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 data set, though.

The possibility of RMB overvaluation seldom garnered media attention until 2015. In May of that year, the International Monetary Fund (2015) stated that the RMB was at a level that is ‘no longer undervalued’. 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 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 PWT 8.1 data set does not differ substantially from those obtained from Table 7. However, the big differences arise when using the WDI

TABLE 8 Chinese RMB misalignment in the presence of control variables

	PWT 7.0 full	PWT 7.0 developing	PWT 8.1 full	PWT 8.1 developing	WDI full	WDI developing
Panel A: Linear specifications with control variables						
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)
Panel B: Quadratic specifications with control variables						
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.

data set—the RMB was overvalued by more than 30% in 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.²⁴

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 non-linear Penn effect. We focus on the recently available PWT 8.1 data set, 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 relationship is non-linear; a quadratic term, implying a U-shaped relationship that is apparent from visual inspection of the data.

The nature of the non-linearity displayed by developed and developing economies differs. For developed economies, the quadratic term implies an inverted U-shaped relationship between real exchange rate and income. Developing economies, on the other hand, display a U-shaped relationship. Additional analyses suggest that the non-linearity 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 data set. The documented non-linear Penn effect, especially the differential non-linear behaviours 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 weaker (stronger) evidence of RMB undervaluation (overvaluation), especially when examining the full sample of countries. Our estimates show that RMB may have embarked on its overvaluation trend as early as 2011, if not 2009.

In terms of prospects for the RMB, as long as Chinese per capita growth exceeds that of the United States, the long-run equilibrium value of the RMB will continue to rise, holding constant other factors such as financial openness and levels of corruption. Each 1 percentage point increase in Chinese per capita income relative to the United States results in a 0.25% increase in the price level.²⁵

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

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ENDNOTES

- 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 varies 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).
- ³ See Rogoff (1996) for a survey of the PPP literature.
- ⁴ Dunaway, Leigh, and Li (2009) conduct an extensive analysis, highlighting the sensitivity of the results to differing assumptions.
- ⁵ Holding $(p_N^* - p_T^*)$, and with tradable prices equalized, our 'price level' variable r is equal to $\alpha\omega$.
- ⁶ 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 non-tradables price index.
- ⁷ Frankel (2006) discusses whether one can speak of an 'equilibrium exchange rate' when there is more than one sector to consider.
- ⁸ 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., 2015). The GK procedure will tend to understate PPPs in poor countries and thus the prices it gets could be biased towards rich country prices (Deaton & Heston, 2010).
- ⁹ 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 are available upon request. Excluded countries include: Bahrain, Bermuda, Brunei, El Salvador, Equatorial Guinea, Kuwait, Oman, Qatar, Saudi Arabia, Slovenia in 1990, and Zimbabwe from 2008 to 2011.

- ¹⁰ In both studies, the absolute level of per capita income is used instead of relative per capita income.
- ¹¹ They argue that the test for the exact necessary and sufficient conditions for a U shape requires the slope of the curve to be 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.
- ¹² Dekle and Ungor (2013), for example, offer an alternative perspective on the role of agriculture sector productivity in assessing the Penn effect.
- ¹³ 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.
- ¹⁴ Developed and developing economies can also display different patterns of exchange rate misalignment estimates (Cheung & Fujii, 2014a).
- ¹⁵ 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.
- ¹⁶ 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.
- ¹⁷ The implications of measurement errors for Penn regression and related misalignment estimation are illustrated by Cheung and Fujii (2014a). Further averaging can alleviate the biases from serial correlation in the data which can affect the within estimator.
- ¹⁸ Note that the so-called Penn effect is documented across cities within a country (Cheung & Fujii, 2014b).
- ¹⁹ The remoteness index is calculated by first taking the minimum average distance of country to the world market, logging and applying a min-max procedure, and then applying a coefficient of 15% to landlocked countries. See United Nations Department of Economic and Social Affairs (2015).
- ²⁰ Since no advanced economy is 'remote' by the criterion we use, the advanced economy results are unchanged.
- ²¹ The results are largely unchanged when remoteness is applied as a continuous variable, with the adjusted R^2 slightly lower, and the corruption coefficient becomes statistically insignificant.
- ²² In our view, financial openness is the viable candidate for endogeneity, which does not enter with statistical significance in the estimates. Hence, we do not believe any of our conclusions regarding determinants of the price level, or the degree of misalignment, hinge critically on this issue.
- ²³ To retain comparability with other estimates, we rely on estimates from specifications omitting the remoteness variable.
- ²⁴ The implications for misalignment assessment differ across countries. Cheung and Fujii (2014a), for example, show misalignment estimates can be affected by a few economic variables and measurement-related factors.
- ²⁵ This calculation relies upon the specification in column (4) of Table 6 (augmented quadratic specification, estimated on developing country sample), and using China-US relative per capita income for 2011.

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APPENDIX 1: DATA AND SOURCES

The primary source for the data is PWT 8.1. A secondary data source is PWT 7.0, 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 United States.

The basic sample drawn from PWT 8.1 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, Oman, Qatar, Saudi Arabia, Slovenia in 1990, and Zimbabwe from 2008 to 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 draws on United Nations 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 a value of 1 when remoteness exceeds 0.75, and 0 otherwise.