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An assessment of the claimed renminbi misalignment through the application of the Penn effect model

Mandeep Grewal and Marielle Hvide

Supervisor: Ingvild Almås

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NORWEGIAN SCHOOL OF ECONOMICS

Abstract

In this thesis we explore the claimed renminbi misalignment through the application of the Penn effect model. The Penn effect model estimates equilibrium exchange rates by exploiting the empirical relation between real incomes and price levels. This thesis has three contributions to the excising literature on the topic. Firstly, we apply the most recent and comprehensive data set available for international price comparisons, published by the International Comparison Program (ICP) in May 2014. This is believed to improve the reliability of the misalignment calculation by reducing measurement errors in price levels. Secondly, the functional form of the Penn effect is investigated in detail. Thirdly, a method of correcting measurement errors in real incomes and price levels is presented. This is done by exploiting the strong empirical relation between food share and income, named the Engel's Law.

The analysis yields two contrasting findings. First of all, the Penn effect in the ICP data is best approximated by a dummy regression allowing for different slope and intercept between OECD and non-OECD countries. The regression result indicates that the Chinese renminbi is broadly in line with the real exchange rate predicted by the Penn effect. Consequently, the Chinese renminbi can no longer be considered undervalued according to this measure.

The second main finding of the analysis does, however, cast doubt on the reliability of this result. According to the Engel corrected incomes and price levels, the Penn effect is best approximated by a non-linear regression function. The non-linear regression on the Engel corrected data indicates that the renminbi is still strongly undervalued by about 50 percent.

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1. Introduction

China has a history of exchange rate regimes with strict capital controls and foreign exchange interventions. China has long been accused for maintaining exchange rate policies that limits the appreciation of its currency, the renminbi, against other currencies. Some analysts contend that China deliberately manipulates its currency in order to gain unfair trade advantage over its trading partners. They further argue that China's currency policy has been a major factor for the global financial imbalances. Foremost with the allegations has been the U.S. – China's leading trade partner. They have long been arguing that the renminbi is significantly undervalued against the U.S. dollar and that the undervaluation has constituted the large annual U.S. trade deficits with China (Morrison and Labonte, 2013).

There is extensive literature that discusses these allegations and tries to seek an answer of whether or not the renminbi is deliberately manipulated. Up until 2010, most estimates of the renminbi misalignment revealed a considerable underestimation of the renminbi. Cline and Williamson(2010), Subramanian (2010), Bergsten (2010) and Cheung et al. (2010), all found that the renminbi was undervalued against the U.S. dollar by 30, 40 and 50 percent respectively, pre 2010.

In recent years, China has moved towards a liberalized capital account and a more flexible exchange rate regime, hence, these results have been noticeably revised. Whether the renminbi can be entitled as undervalued, is now highly debated. Cline and Williamson (2011) find that the renminbi was undervalued by about 28 percent in 2011, while Kessler and Subramanian (2014) conclude that the renminbi was no longer misaligned. Misalignment estimates for the same year provided by the International Monetary Fund (IMF) ranged between 3 percent overvalued to 23 percent undervalued (IMF, 2011).

This thesis seeks to contribute to the current debate of the renminbi misalignment through the application of the Penn effect model of currency misalignment. The Penn effect model estimates equilibrium exchange rates by exploiting the empirical relation between real income and price levels. The price level is by definition the real exchange rate, making it possible to infer currency misalignment as the difference between a country's observed price level and the price level predicted by the model.[1] Consequently, the real exchange rate of

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[1] See Eq. 6 for definition.

countries with price levels lower than what the Penn effect model predicts are considered undervalued.

The empirical relation was first established by Milton and Kravis (1954) in the first Penn world table; a data series-providing price and income data for international comparison. The observation was later backed theoretically through the Balassa-Samuelson (B-S) theorem. The theorem explains the observed systematical differences in price levels based on productivity differentials between traded and non-traded sector.

Although the Penn effect model has been widely applied in estimating the renminbi misalignment (see among others Frankel (2006), Coudert and Couharde (2005), Subramanian (2010)), this thesis seeks to provide three important contributions to the excising literature on this topic.

First of all, this thesis applies the most recent and comprehensive data set available for international price comparison. The price level and income data was released by the International Comparison Program (ICP) in April 2014, based on an extensive price surveys of 177 participating countries. Restricting the analysis to a cross-country sample over the most recent ICP data reduces the problem of measurement errors in the data (Johnson et al. 2009). This is believed to improving the reliability of the misalignment calculation remarkably compared to previous estimates based on extrapolated data from the last ICP survey in 2005.

Secondly, the functional form of the Penn effect is investigated in detail.[2] There has been little discussion on the functional form of the Penn effect and most scholars have estimated the relation as a log-linear regression function over a full sample of countries. The relation between income and price levels in the 2011 ICP data does, however, not seem to be linear over the full sample. Consequently, three different regressions are compared and discussed in detail; a linear, non-linear and a regression allowing for different Penn effects between OECD and non-OECD countries. The misalignment of the real renminbi is then estimated based on the most appropriate functional form for the Penn effect.

Lastly, a method to correct bias in income and price levels is proposed. Since the price level enters into both the explained and explanatory variable of the Penn effect regression, the

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[2] The Penn effect is defined as the change in the price level following a change in real income.

results are extremely sensitive to measurement errors in the price levels. Although restricting the analysis to a cross-country sample over the 2011 ICP data mitigates this problem, previous versions of the ICP data have been shown to entail considerable measurement errors (See for instance Feenstra et al (2013) and Deaton and Heston (2010)). Little research has, however, been published on the robustness of the 2011 data.

In this thesis, the well-established empirical relation between food share and income, named the Engel curve, is used to provide alternative price level and income estimates for all countries.[3] Since the income elasticity of food is low, the proportion of income spent on food decreases as income increases, hence there exists a negative relation between food share and real income. The Engel curve has been broadly supported in the literature and has been widely applied to measure bias in price levels (See for instance Hamilton (2001), Costa (2001) Almaas (2012) Nakamura et al. (2004)). By constructing a new data set based on the price levels and real incomes predicted by the Engel curve, we purpose a new Penn effect and misalignment estimate for the Chinese renminbi.

The analysis yields two contrasting findings. First of all, the Penn effect in the ICP data is best approximated by a dummy regression allowing for different slope and intercept between OECD and non-OECD countries. The relation between income and price levels is found to be much stronger in OECD countries than for non-OECD countries. The regression result indicates that the Chinese renminbi is broadly in line with the real exchange rate predicted by the Penn effect. Consequently, the Chinese renminbi can no longer be considered undervalued according to this measure.

The second main finding of the analysis does, however, cast doubt on the reliability of this result. According to the Engel corrected price levels and incomes, the Penn effect is best approximated by a non-linear regression function. The non-linear regression on the Engel corrected data indicates that the renminbi is still strongly undervalued by about 50 percent. This is a stark revision from the misalignment found for the 2011 ICP data. Furthermore, the relation between price levels and incomes is much weaker in the new data. This raises an important question on the existence of the strong relation between incomes and price levels and the application of the model to estimate currency misalignment.

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[3] The relation is also named the Engels law. The name stems from the statistician Ernest Engels who first proposed the relation.

This thesis is organized as follows. The first section gives an overview of relevant theory on global imbalances, exchange rate determination and regimes. The Penn effect model for currency misalignment is here presented. The second section presents a brief overview of the history of China's economy and exchange rate policies. China's role in the global imbalances is also discussed in detail and the most recent estimates of the real renminbi are presented. In the third section, the misalignment of the real renminbi is determined by the application of the Penn effect model. In section four, the robustness of the result to measurement errors in the data is discussed and the Engel method for correcting price levels is presented. The misalignment of the renminbi is then discussed in light of the new findings. Section five concludes.

2. Theory

In this section we provide the theoretical background for the discussion and analysis of the renminbi misalignment. Due to the alleged role of China in the global imbalances, this sections starts off by presenting how and why these imbalances may occur. Secondly, we deliberate on the theory of exchange rate determination both in the short run and long run. The Penn effect model is here presented. Lastly, we give an overview of different exchange rate regimes and the impossible trinity. This is for the reader to better understand how China's choice of exchange rate policy has contributed to their economical transformation and possibly the global economic imbalances.

2.1 Balance of payments and global imbalances

2.1.1 Balance of payments

A country's balance of payment can be divided in two parts: the current account and the capital and financial account. The current account refers to the monetary value of international flows associated with transactions in goods, services and income flows. The transactions related to international purchases or sales of assets[4] are registered on the capital and financial account (Backus, 2014).

The capital and financial account measures the net flows of financial claims, stating a country's net international investment position or, for simplicity, net foreign assets. Taken together, the balance of payment registers all currency inflows and outflows of a country and as the name suggests, the balance of payment must always be in balance. It follows that if there is a surplus on the current account (surplus of foreign currency), the capital and financial account must register a deficit (deficit of foreign currency), essentially leading a country to become a net lender to the world.

(1)   *Current account + Capital and Financial account = 0*

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[4]   The term asset is broadly defined to include items such as titles to real estate, corporate stocks and bonds, government securities, and ordinary commercial bank deposits.

2.1.2 Global imbalances

In the same way as the balance of payment of a country must balance, the world aggregated current accounts and capital and financial accounts must also balance. This means that if one country is a net borrower, other countries must be net lenders. Countries can run considerable deficits or surpluses on their current account over many years, and this is what is referred to as external imbalances or global imbalances.

According to trade theory, whether a country is a net borrower or lender depends on the country's intertemporal preferences for consumption and differences in production possibilities. A country that has a low production capacity today, but will have a higher capacity in the future (typically a developing country) will be better off borrowing from another country that is in the opposite position (typically a developed country). The lending country will also be better off since they will receive higher interest rates than what they would have in autarky (Obstfeld & Rogoff, 1996).

In relation to business cycles, rapid growth of production and employment is commonly associated with large or growing trade and current account deficits, whereas slow output and employment growth is associated with large or growing surpluses (Carbaugh, 2013). Periods of rapid economic growth are likely to be periods in which new investment is highly profitable. However, investment must be financed with saving, and if a country's national saving is not sufficient to finance all new investment projects, the country will rely on foreign savings to finance the difference. Since the investments are likely to be profitable, foreign countries will be motivated to invest their excess savings in order to gain higher returns. Hence, the country will experience a net financial inflow and a corresponding current account deficit.

2.2 Exchange rate determination

As long as monetary authorities do not attempt to stabilize exchange rates or moderate their movements, the equilibrium exchange rate is determined by market forces of supply and demand in the foreign exchange market. In practice, it is unlikely that the exchange rate will remain in its equilibrium over a longer period of time. The underlying forces that determine the allocation of the supply and demand tend to change over time, causing deviations from

the exchange rate equilibrium. Currencies that deviate from their equilibrium are said to either have appreciated or depreciated depending on the direction of the deviation[5].

In order to understand why some currencies depreciate and others appreciate; it is important to examine the underlying factors that cause changes in the supply and demand of currencies over time. These underlying factors can be divided in two main groups; *market fundamentals and financial factors* (Carbaugh, 2013). Market fundamentals (economic variables) are factors that affect the supply and demand for exports and imports, such as productivity and price level differentials, consumer preferences and government trade policies. Financial factors on the other hand are factors that affect the demand and supply of domestic and foreign currency, such as interest rate differentials and capital constraints.

In addition to the factors mentioned above, expectations are likely to have an effect on the supply and demand for currencies (Hopper, 1997). Foreign exchange markets react to all news that may have a future effect on economic variables (See box 1 for a definition of foreign exchange market). Financial transactions will, however, be generally more responsive to news than trade related transactions. Market fundamentals are hence more appropriate to explain long run exchange rate movements, whereas the financial factors are more accurate in explaining short run movements.

Box 1. Foreign exchange market

The foreign exchange market is refers to as the organizational setting where individuals, businesses, government and banks buy and sell foreign currencies. This is an important element in the process of conducting international transactions related to for instance goods, services and assets[1]. In the foreign exchange market the exchange rate simply represents the price of foreign currency in terms of the domestic currency (Backus, 2014).

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[5] A country's exchange rate equilibrium may differ depending on what method that is applied to determine the equilibrium.

2.2.1 Long run exchange rates

As mentioned above, long run exchange rates tend to react to changes in four key economic variables: relative productivity, price levels, consumer's preferences and trade policies. In the following section the relative price levels between countries and their effect on exchange rates will be discussed in more detail. This aspect is deliberated more closely due to its relevance for later analysis and discussions.

Purchasing Power Parity

Purchasing power parity (PPP) is a theory of exchange rate determination and has a long history in economics, dating back to the 16th century. The specific terminology of PPP was, however, introduced in the years after World War I. It was motivated by the large-scale inflations during and after the war, which led to an international policy debate concerning the appropriate level for nominal exchange rates among the major industrialized countries (Cassel, 1918).

PPP states that a change in the exchange rate between two countries is determined by the change in the two countries' *relative price levels*. In an integrated, competitive market the strict or absolute version of PPP relies on the "law of one price". In the absence of transaction costs, competitive arbitrage should force the same good to sell for the same price across countries (Lafrance & Schembri, 2002). To illustrate the law of one price let p_i and p_i^* represent the price of good i in domestic and foreign currency respectively, and E the exchange rate.[6] The law of one price can hence be expressed as follows:

(2) $\qquad p_i = p_i^* E$

Under special cases the law of one price extends not only to individual goods but also to aggregate prices (Dornbusch, 1985). To illustrate, let P and P^* represent the aggregate price at home and abroad in their respective currencies. The aggregate price is then given by the following equations:

(3) $\qquad P = \sum_{i=i}^{n} w_i \, p_i \qquad P^* = \sum_{i=i}^{n} w_i \, p_i^*$

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[6] The exchange rate expressed as number of units of home currency price per one unit of foreign currency.

The domestic and foreign aggregate price is obtained by taking a weighted average of the prices of the n commodities in a basket. If the prices of each good, quoted in the same currency, are equalized across countries and the same goods enter each country's market basket with the same weight (i.e. homogenous of degree one) then the law of one price can be extended to aggregate price levels. The law hence takes the form of the absolute version of PPP.

$$(4) \qquad E = \frac{P}{P^*} = \frac{Domestic\ price\ of\ a\ standard\ market\ basket\ of\ goods}{Foreign\ price\ of\ the\ same\ standard\ basket}$$

Furthermore, when the price of the market basket in two countries is measured in a common currency, the aggregate prices will be the same. Consequently, a real exchange rate (RER) equal to one is obtained.

$$(5) \qquad RER = \frac{EP^*}{P} \approx 1$$

The RER defined as the relative price of a common basket of goods denominated in the same currency across countries, is one of the most important and debated prices indices in international economics (Pancaro, 2011). A RER computed as in the equation above is often used to judge whether a county's price level is reasonable. If the aggregate price in the home country is higher than abroad, a $RER < 1$ is obtained, and the home currency is said to be overvalued. If the aggregate price however is lower in the home country, $RER > 1$, and the home currency is said to be undervalued. Over- and under- valued here means relative to the theory of absolute PPP. Therefore, RER variations represent deviations from the PPP equilibrium.

As a theory of exchange rate determination, absolute PPP predicts, as mentioned above, that the nominal exchange rates will adjust in order to equalize price levels. However, in practice, absolute PPP does not hold for a number of reasons, at least not in the short run. Consequently, this limits its usefulness as a theory of exchange rate determination.

First of all, if prices are sticky in the short-run, movements in the nominal exchange rate will affect the real exchange rate. Second, the theory assumes that all goods are traded internationally, however, in reality this is not the case. When prices of non-tradable goods

change, the price indices change as well. However, changes in prices of non-tradable goods do not affect the international trade flows. Consequently, the predicted nominal exchange rate responses to bring the real exchange rate back to unity dos not occur. Hence, the expected result under PPP where the nominal exchange rates change due to changes in price levels is not observed.

Third, the presence of significant transaction costs for tradable goods, including transportation costs, tariffs, taxes and other non-tariff trade barriers limit the extent to which differences in prices across countries are eliminated by international movement of goods. Last but not least, the theory of PPP is based on goods flows, and does not take capital flows into account. Capital flows do, however, have a significant effect on exchange rate movements in the short run – causing deviations from PPP.

From the discussion of the shortcomings of the theory, it is clear that there may be significant deviations from the PPP in the short run. This explains why the theory is more appropriate for long run exchange rate determination. There are, however, also factors that are believed to cause deviations from the PPP in the long run. Consequently, most currency models estimating long run exchange rates incorporate one or more of these factors. Within this group of models we find the widely used and recognized *Penn effect model*.[7]

The Penn effect model

The Penn effect model exploits the observed positive relation between a country's income and price level. When all countries' price levels are converted to a common currency at the prevailing nominal exchange rates, rich countries tend to have higher price levels and poor countries tend to have lower price levels. This result was first documented for twelve developed countries by Belá Balassa (1964) in a seminal paper and was later confirmed for a large sample of countries as soon as data from the Penn World Table (PWT) became commonly available (see for instance Summers et al. (1991), Barro (1991), Rogoff (1996) and Frankel (2006)).

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[7] Extended versions of the Penn effect model including several explanatory variables are referred to as behavioral equilibrium exchange rate models (BEER). These models are also widely used in estimating currency misalignment.

Box 2. The International Comparison Program and Penn World Table

The main objective of the International Comparison Program (ICP) is to provide comparable data on the level of gross domestic product (GDP) and its components, denominated in a common currency for all participating countries. It specifically aims to provide estimates of purchasing power parities (PPPs) of currencies to measure and compare price levels and real expenditures. The data is collected based on extensive price surveys and national accounts data.

The program was first established in 1968 as a joint venture between the United Nations (UN) and the international comparison unit of Pennsylvania University. In the first ICP round in 1970, the price surveys were only conducted in 10 countries. Since then, the program has evolved to become a truly global program covering 177 countries from all regions of the world in the ICP 2011 round (ICP.org).

The Penn world tables (PWT) are extensive datasets of national accounts economic *time series* covering a wide range of countries from all parts of the world. All expenditure data is denominated in a common set of prices and currencies, facilitating real comparison. Since the first ICP benchmark study was conducted, these have been the basis for the extrapolations of PPP for non-benchmark years and countries in the PWT (University of Pennsylvania, 2014).

The Penn effect model is based on absolute PPP and is the most basic and influential model for assessing exchange rates misalignment. Given the definition of RER in Eq. (5) it can also be referred to as a country's price level (PL).[8]

$$(6) \qquad PL = RER = \frac{P/P*}{E} = \frac{PPP}{E}$$

If RER is equal to one, the nominal exchange rate, E, is equal to its PPP rate and is at equilibrium; otherwise, it is over- or undervalued. In a Penn effect model for currency misalignment the price levels are regressed on countries' real GDP per capita (Rogoff 1996). The Penn effect regression is commonly specified as in Eq. (7):

$$(7) \qquad \log(RER) = \alpha + \beta \log(GDPP) + \varepsilon$$

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[8] Strictly speaking the real exchange rate defined as in Eq. 6 is the inverse of the price level. For simplicity, the price level and the real exchange rate are equated in a manner that a depreciation of the real exchange rate represents an improvement of a country's competitiveness.

In Eq. (7), *RER* is defined by Eq. (6) and GDPP is real gross domestic product (GDP) per capita representing a country's income level or economic development stage. Deviations from the regression line represent over- or undervaluation of the real exchange rates. Furthermore, since the real exchange rate incorporates differences in price levels, an undervalued real exchange rate represents a competitive advantage in trade.

There is a consensus among economists on the existence of the Penn effect, however, the reasons for its occurrence has been explained from different perspectives. Belá Balassa and Paul Samuelson presented the most recognized explanation in two individual papers in 1964, which latter was named the Balassa-Samuelson theorem. They explain the deviation from PPP through international differences in relative productivity between tradable and non-tradable sector (Rogoff, 1996).

Balassa-Samuelson theorem

The Balassa-Samuelson (B-S) theorem states that the price levels are lower in low-income countries due to lower productivity. In order to understand the basic logic of the theorem it is important to explain the assumptions it is built upon. The first assumption is that there is a fundamental distinction between goods produced in the tradable and non-tradable sector. While the tradable sector is dominated by manufacturing, the non-tradable sector mainly comprises of services, which cannot be exported. The prices of tradable goods (P_t) will therefore be determined on the world market, whereas prices of non-tradable goods (P_n) are determined domestically.

The second assumption is derived from standard economic theory that people are paid the same wages and that the wages are paid according to the marginal productivity of labor (Ickes, 2004).[9] Hence, within a country with perfect labor mobility the nominal wages in tradable and non-tradable sector must equalize (see Eq. 8). Furthermore, it is assumed that the productivity in services is similar across countries, so that the marginal productivity in non-tradable sector (MPL_n) is exogenously given and equal across the world.

$$(8) \qquad MPL_t * P_t = MPL_n * P_n \qquad (w = MPL * P)$$

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[9] Marginal productivity of labor (MPL) implies how much a company is able to produce per unit of labor. An increase in the productivity yields an increase in the MPL, and vice versa.

As a country develops and increases its interaction with the global economy, the marginal productivity of labor in tradable sector (MPL_t) will tend to increase relative to non-tradable sector. The productivity growth in tradable sector occurs due to technological spillovers and "know how" through international trade.[10] With two variables exogenously given, MPL_n and P_t, an increase in productivity in tradable sector will result in an increase in prices in non-tradable sector, in order to equalize wages. Hence, the price of non-tradable goods increases relatively to prices of tradable goods (Rogoff, 1996). Since the price level of a country is given by the prices of both tradable and non-tradable goods, it will experience an increase in its price level and hence an appreciation of the real exchange rate.

Beside Balassa and Samuelson, there are also other scholars that seek to explain the observed relationship between income and price levels (see for instance Kravis and Lipsy (1983) and Bhagwati (1984)). The explanation given by Balassa and Samuelson is, however, the most widespread and recognized theoretical explanation for the Penn effect.

2.2.2 Short run exchange rates

The short run exchange rates are the exchange rates that the government seeks to effect when they intervene in the foreign exchange market. Hence, it is of great importance to deliberate what market forces there is that determine the short run exchange rates.

As mentioned in the previous section, the PPP theory does not consider capital flows when exchange rates are determined. Capital flows can, however, have significant effects on exchange rate movements in the short run. Today, the activity in the foreign exchange market is highly dominated by investors in assets.[11] Investors in financial assets can modify their outlooks of currency values within a short period of time, and hence rapidly change their decision of whether to hold foreign or domestic assets. Consequently, these rapid changes of decisions have a greater role in short term exchange rate determination than international trade flows.

According to the asset-market approach, investors consider two key factors when deciding between domestic and foreign investments: relative levels of interest rates and expected

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[10] "Know how" in this context refers to the knowledge of how to do something both through learning from others and learning through practicing.
[11] Assets such as securities, corporate bonds, bank accounts and stocks.

changes in the exchange rate itself (Carbaugh, 2013). These factors, in turn, account for fluctuations in exchange rates that we observe in the short run.

Interest rate parity

Interest rate parity (IRP) explains the relationship between interest rates and exchange rates. The general principal of IRP is that an investment in foreign and domestic assets should provide equal returns, even if the underlying assets pay different interest rates. IRP can be divided into two groups; covered interest rate parity and uncovered interest rate parity. The main distinction lays in the pursued investment strategy, arbitrage and speculation respectively (Backus, 2014).

The theory of covered interest rate parity (CIP) plays an essential role in foreign exchange markets, connecting interest rates, spot exchange rates and forward exchange rates. The theory states that it exists an equilibrium relationship were the interest rate differential between two countries is equal to the differential between the forward exchange rate and the spot exchange rate. CIP is an arbitrage condition due to the fact that investors may capitalize on interest rate differentials between two countries as long as the equilibrium is not reached. In addition, investors will cover themselves against exchange rate risk so that any adverse movement of the denominated currency in relation to the base currency does not affect them.[12] This is done by selling the currency with the relatively higher interest rate forward. The covered interest rate parity condition may be expressed as follows:

$$(9) \qquad i - i^* = \frac{F_t - S_t}{S_t}$$

$S -$ Spot exchange rate, which is the price of the foreign currency at the prevailing market rate.

$F -$ Forward exchange rate, which is the predetermined price of foreign currency to be exchanged at a specified date in the future.

$i -$ Interest rates in the home country

$i^* -$ Interest rates in the foreign country

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[12] The base currency is the primary currency quoted in a currency pair on foreign exchange. For instance, in the following currency pair, renminbi/USD, renminbi will be the base currency and USD the denominated currency.

In equilibrium, investors cannot use covered interest rate arbitrage to achieve higher returns than those achievable in their respective home countries, because any interest rate advantage in the foreign country will be offset by a discount in the forward exchange rate.

Uncovered interest rate parity (UIP) is reached when investors are indifferent between the choice of investing in domestic assets and foreign assets. The theory states that the expected return of an unsecured position in a foreign asset should retain the same return as a position held in domestic assets. This implies that the investors do not secure their positions in foreign assets in relation to exchange rate risks. Furthermore, the theory states that interest rate differentials between two countries should be offset by the expected future exchange rate. If there were an opportunity to achieve higher profits by taking advantage of interest rate differentials between countries, investors would like to invest in the assets providing the largest expected return. This capitalization would continue until the equilibrium is reached.

$$(10) \qquad i - i^* = \frac{E[S_{t+1}] - S_t}{S_t}$$

$E[S_{t+1}] -$ Expected spot exchange rate at time $t + 1$.

$S_t -$ Spot exchange rate at time t.

In order for the equilibrium to be restored the country with the relatively higher interest rate has to face a depreciation of its currency, so that the expected return is equal to the return achieved in the low interest rate country. However, in reality high interest rate countries on average face an appreciation, because of the capital inflow (Backus, 2014). This is one of the reasons why UIP may not always hold. In the case where interest rate parity does hold it still might not be profitable due to transaction costs, currency restrictions and tax laws.

The Fisher effect

The fisher effect states that the nominal risk-free interest rate, i, is equal to the real interest rate, r, plus inflation, π. Irving Fisher was the first to interpret the underlying relationship between the nominal interest rate and the purchasing power parity of money measured as inflation (Hatemi, 2009). The theory furthermore states that real returns are equalized across countries because of arbitrage. This implies that, in order for the theory to hold, the international capital markets need to be perfectly integrated. If the real return is higher in one

country compared to another it will lead to capital inflows to the country with the relatively higher return until the expected real returns are equalized. The fisher equation is formalized as follows:

(11) $\qquad i = r + \pi$

The fisher effect does have its drawbacks because it does not always hold. The assumption regarding perfect capital markets is not always the case in reality. This can be explained by factors that can prevent capital from moving freely between countries, such as transaction costs, taxes, currency risk and legal constraints, referred to as capital controls. Hence, real interest rate differentials between countries do exist.

Foreign exchange intervention

When the government intervenes in the foreign exchange market, the exchange rate may deviate considerably from the equilibrium level determined by market fundamentals. Foreign exchange intervention is a tool used by the government in order to influence the short run exchange rates. The interventions can be motivated by events that cause misalignments in the currency and/or instability in the economy and financial markets. Such events can for instance be massive capital inflow, which affects both the currency and the stability of the economy. Capital inflows often lead to an appreciation of the currency, which in turns result in weakened competitiveness for the tradable sector. Furthermore, it may hurt the economy by creating inflation, hence the government intervenes in order to correct these distortions.

There are different ways to intervene the foreign exchange market and they are mainly classified as direct or indirect interventions. Under a direct intervention the central bank intervenes directly into the foreign exchange market by buying or selling the domestic currency (Suranovic, 2013)**.** Direct intervention can, however, be conducted in two ways: unsterilized or sterilized. Unsterilized interventions allows for changes in the monetary base caused by the foreign exchange interventions, whereas the sterilized interventions are aimed at neutralizing these impacts.

To take an example, consider a country that wants to depreciate its domestic currency due to an overvaluation. The country can do so by selling its home currency in exchange for foreign currency. This in turn will increase the supply of the home currency, resulting in a depreciation of the home currency relatively to the foreign currency. This intervention is an

example of an unsterilized intervention that will increase the monetary supply. The central bank can, however, prevent this effect by sterilizing the intervention, which can be done by implementing contractionary monetary policy that will extract the excess money supply.

The indirect foreign exchange interventions affect the exchange rate movements by altering the money supply (Suranovic, 2013). An increase in the domestic money supply will increase the supply of the domestic currency and thus result in depreciation. Similarly, a decrease in the money supply will cause the domestic currency to appreciate. The indirect interventions affect the exchange rates through open market operations. Alterations in the money supply will affect domestic interest rates, which in turn contribute in changes in the exchange rates. Since the indirect interventions traverse through market operations it may take a sufficient amount of time to realize their effect on exchange rates.

The degree of intervention in the exchange rates is to some extent determined by the currency regime a country choose to implement. It requires for instance a higher degree of intervention for countries that keep their exchange rates fixed in order to keep the rate at its fixed value. Furthermore, countries that use the exchange rate as a monetary policy tool must counteract misalignments in the exchange rate to retain confidence in the exchange rate regime.

2.3 Exchange rate regimes

An exchange rate regime is the tool used by the government to manage its currency in relation to other currencies. The exchange rate regimes are closely related to monetary policy and they are generally dependent on many of the same factors (market fundamentals and financial factors). Each country that has its own currency has to decide upon what kind of exchange rate regime they want to maintain. The choice of regime is often based on the degree of flexibility a country wants for its currency. The different alternatives have different implications for the extent to which the government intervenes in the foreign exchange market. Based on the degree of flexibility, exchange rate regimes are arranged into three main categories: flexible regimes, intermediate regimes and fixed-rate regimes.

2.3.1 Flexible regimes

Under the category of flexible regimes there are two different sub-regimes; free floating and managed float. Under the free floating regime the government does not intervene in the foreign exchange market, hence the price of the currency is decided by the market forces of supply and demand (Bird, 2002). This implies that there is no exchange rate policy and no target value for the currency. By letting the currency float freely it does not apply any constraints on the domestic macroeconomic policy.

The managed float is closely related to the free-floating regime; however, the government does intervene in the foreign exchange market to moderate excessive fluctuations in the exchange rate (Yagci, 2001). This regime gives the government the opportunity to execute stabilizing interventions without being constrained by any intervention rules, such as how much the currency is allowed to fluctuate or what the exact value of the currency should be. Furthermore, a separate nominal anchor, such as inflation targeting, often accompanies the managed float regime; hence, the regime does not constrain the monetary and fiscal policy in strict manners.

2.3.2 Intermediate regimes

Under the category of intermediate regimes we find crawling band, crawling peg and fixed peg. What differentiates the intermediate regimes from the floating regimes is the degree of intervention, which is slightly higher under the intermediate regimes. The crawling band allows the exchange rate to fluctuate within a predetermined band. The width of the band is often classified as narrow or broad, where the latter one provides more flexibility and hence is closer to a floating system. The exchange rate is maintained around a central rate that is adjusted periodically at a fixed preannounced rate in order to keep the exchange rate competitive (Yagci, 2001). Under the crawling peg regime the independence of the monetary policy will differ depending on the bandwidth, limiting flexibility the narrower the band is.

When a country decides to tie the value of its currency to another country's currency, a commodity (such as gold) or a basket of currencies it is referred to as pegging. A country often chooses to peg its currency to an anchor that is relatively more stable, because it provides more credibility for for instance investors that are afraid to loose profits because of currency fluctuations (Yagci, 2001). Under a crawling peg the par value of the currency is

changed at a predetermined rate or as a function of inflation differentials between countries. This is an attempt from the government to combine flexibility and stability. The crawling peg regime is often used by countries with high inflation, in an attempt to avoid currency appreciation by pegging their currency to low inflation countries. Among the versions of more fixed regimes, the crawling peg is the one that imposes least restrictions; hence it may appear as less credible than the other fixed regimes.

The last member of the intermediate regimes is the fixed peg, where a country chooses to peg its currency at a fixed rate against a single currency or a basket of currencies. The monetary authority is not committed to keep the peg indefinitely, but will however stand ready to defend the peg with direct or indirect interventions when misalignment becomes unsustainable. Under the fixed peg traditional central banking functions are still possible and the rate of the exchange rate may be altered, although relatively infrequently (Bird, 2002). The possibility of devaluation hence may provide a potentially valuable policy tool in terms of responding to large shocks.

2.3.3 Fixed regimes

The fixed regimes comprise of currency board and currency unions or dollarizations, and are the regimes with the least flexibility or no flexibility at all. A currency board is classified as a strict exchange rate regime where the domestic currency is committed to be exchanged at a specified fixed rate of foreign currency. This is a legislative commitment given by the monetary system. Countries that intend to discipline their central bank, as well as solve their external credibility problems, often adopt the currency board. However, the regime can only obtain its credibility if the central bank is able to keep the commitment. This means they must hold a sufficient amount of foreign exchange reserves to cover the entire monetary base, so that they are able to keep the commitment (Yagci, 2001). The currency board regime leaves almost no scope for independent monetary policy.

With no flexibility at all there is the currency union or dollarization[13] regimes. Under a currency union there will no longer be a national currency, but instead a unified currency, such as the Euro in the European Union. Fixing the exchange rate within a currency union

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[13] "Dollarization" describes any regime in which a country replaces its national currency with the currency of another country. In principal this could involve the euro or the yen as well as the dollar.

imposes strict constraints on domestic macroeconomic policy, since an independent monetary policy is no longer an option. The monetary policy is on the other hand conducted with respect to the member countries by the union's common central bank (Bird, 2002). Under a dollarization, however, countries choose to adopt a foreign currency, often the U.S. dollar, hence the name. The reason why some countries choose this option is due to their exceptionally difficult situation, this can be because of very high domestic inflation or loss of credibility in the domestic currency. The arrangement often helps reduce inflation expectations by imposing fiscal discipline and enhancing policy credibility. The countries that choose to adopt this currency regime, as under currency union, lose the possibility of managing their monetary policy independently.

2.4 The impossible trinity

When countries choose their exchange rate regime, they do so by considering its effects on the economy and whether or not it fulfills their policy goals. However, choosing an exchange rate regime is only one out of three possible policy goals. The impossible trinity is referred to as the trilemma related to choosing between the three policy goals – monetary independence, exchange rate stability and financial integration (Obsfeld et al. 2004). It is referred to as an impossible trinity because it is only possible to choose any two of the three goals simultaneously. This is a fundamental contribution of the Mundell-Fleming-framework.[14] The model considers a small open economy that stands above the decision of whether having a fixed or floating exchange rate, and whether to have perfect capital mobility or financial autarky.

The policy choice of having a floating exchange rate is associated with monetary independence and financial integration, which for instance is the case for countries such as the U.S. and Norway. The policy choice of giving up monetary independence is obtained by having a pegged exchange rate regime and financial integration. Countries pursuing this policy will, however, not be able to manage their monetary policy independently. This is for instance the case for the countries forming the European Union. The last choice of having closed financial markets is associated with having a fixed exchange rate regime and by that letting the monetary policy be autonomous. This was often a preferred choice among

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[14] An economic model first proposed by Robert Mundell and Marcus Fleming. The model reflects the short-run relationship between an economy's nominal exchange rate, interest rate and output.

developing countries in the late 1980s, due to their unstable economic situations with high inflation and incredible exchange rates.

To take an example, consider a country that is pursuing the goals of maintaining financial integration and a stable exchange rate, by holding the exchange rate at a fixed predetermined rate. In an attempt to stimulate the economy the central bank increases the monetary supply, which in turn decreases the real interest rates. As a result investors will start selling domestic assets in search of higher foreign returns. Under a fixed exchange rate regime, the central bank must intervene in the foreign exchange market in order to satisfy the demand for foreign currency at the official fixed rate that has been set. The central bank therefore sells foreign currency to the public in exchange for domestic currency, which is excessively supplied due to the attempt of stimulating the economy. The net effect under a fixed exchange rate regime is hence that the central bank loses control over the money supply. Consequently, the country must give up monetary policy in order to simultaneously have a fixed exchange rate and financial integration.

A country can, however, achieve exchange rate stability and at the same time maintain monetary independence by giving up financial integration. When a country gives up perfect capital mobility, it prevents arbitrage to occur and hence separate the domestic and foreign real interest rates (Aizenman, 2011). In this case the monetary policy operates in the same way as in a closed economy, where in the short run, the central bank controls the supply of money, and a monetary expansion, as in the case above, reduces the domestic interest rate. However, the foreign and domestic interest rates will not equalize due to capital controls and/or restrictions that prevent financial integration.

It is argued that in reality countries do not strictly face a binary choice as argued by the trilemma, but rater choose the *degree* of financial integration and exchange rate flexibility. Countries that choose the strict versions of the fixed exchange rate regimes, for instance such as the currency-board, do not strictly follow the implications of the regimes, due to incidence where the currency loses its credibility. Similarly, countries that choose a flexible exchange rate regime may actively intervene in the foreign exchange market in order to influence the exchange rates. In that way they are able to somehow maintain all three goals. Furthermore, most countries operate in a gray range of partial financial integration, where regulations and capital controls restrict flows of funds across boarders.

Policy choice:
Closed financial markets

Policy goal:
Monetary independence

Policy goal:
Exchange rate stability

Policy choice:
Floating exchange rate

Policy choice:
Give up monetary independence

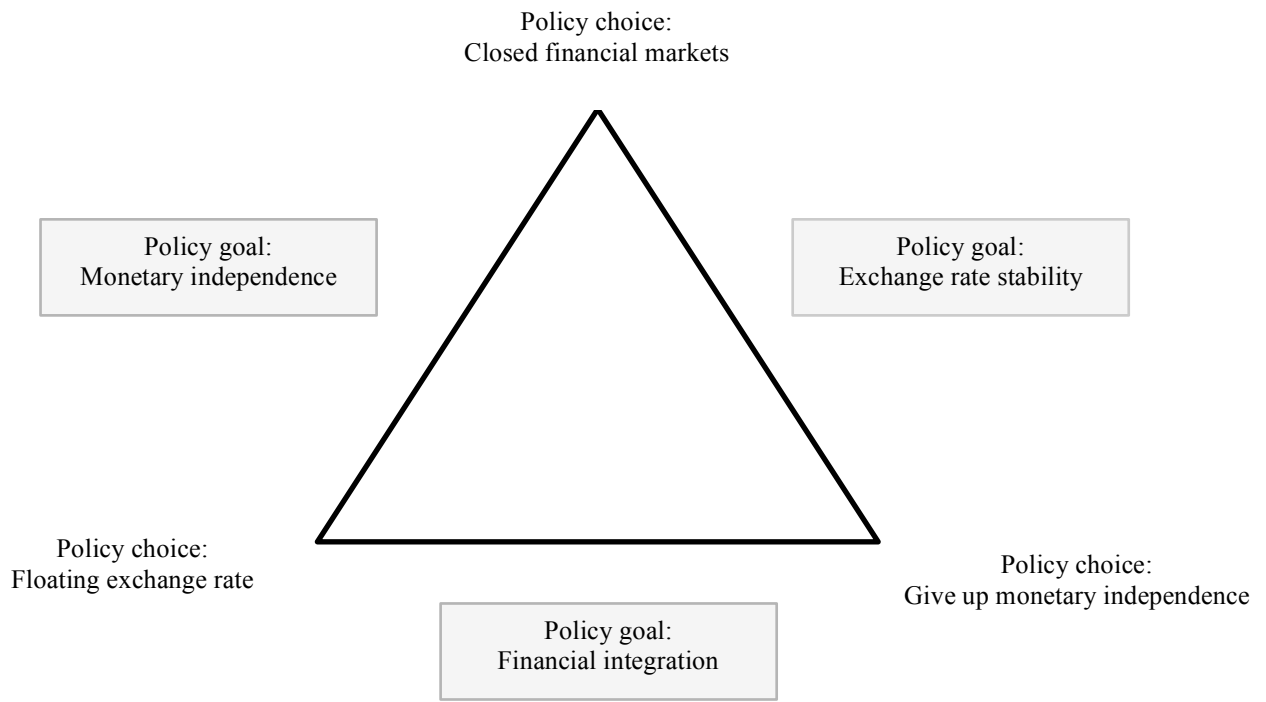Policy goal:
Financial integration

Figure 1: The impossible trinity

3. China

In this section China's history in terms of economic development and exchange rate policies will be deliberated. The purpose is to give the reader an insight into China's growth and present various factors that may have contributed to a misaligned renminbi. First, we present China's choice of exchange rate regime, their capital controls and foreign exchange interventions. Second, there will be a discussion of how these factors and potentially other factors may have contributed to the global economic imbalances. Last, we review some of the most recent estimates of the renminbi misalignment.

3.1 Economic development

Over the past few decades China has evolved to become one of the largest economies in the world. In 1979 China went through an economic liberalization by initiating economic reforms that encouraged interaction with the global economy. These reforms opened up to foreign trade and investment, which in turn has led China to be among the fastest growing economies in the world. In recent years, China has become a major global economic and trade power. It is currently the world's largest merchandise trading economy, second-largest destination of foreign direct investment, largest manufacturer, largest holder of foreign exchange reserves, and it is projected to become the world's largest economy in 2014 (Morrison, 2014).

China's rapid growth and transformation towards a highly powerful economy has had several implications for their trading partners, especially the U.S.. The rise of China has on one hand contributed to a large export market by being a final point of assembly in the global supply chain for U.S. firms. In addition, China holds a large amount of U.S. Treasury securities, which have helped the federal government to finance their large budget deficits. However, some analysts have been concerned that China might have been maintaining protectionistic policies and kept an undervalued currency, thereby undermining U.S. economic interests (Morrison, 2014). Furthermore, they believe that these policies have been the main driver of the massive global imbalances the world economy is experiencing today.

The main concerns related to China's contribution to the global imbalances are associated with their exchange rate policy and whether they have been deliberately manipulating their

currency. In order to discuss these accusations in more detail, China's exchange rate policy and their capital controls will be deliberated more closely.

3.2 Exchange rate regime

The Chinese exchange rate regime has evolved significantly along the past few decades. Prior to 1979 the Chinese renminbi was kept at a fixed overvalued level as part of an import substitution industrialization strategy (Goldstein & Lardy, 2009).[15] This policy, however, kept the economy poor, stagnant, centrally controlled and relatively isolated from the global economy. When the reforms and liberalization policy began the official renminbi rate was devaluated repeatedly as a response to economic fundamentals. Since the liberalization of trade in 1979, China's exchange rate regimes can be divided in three main phases, i.e. a dual-exchange rate regime, a fixed peg regime and a market-based managed float regime (Gang, 2008).

In the first phase, prior to 1994, China maintained a dual exchange rate regime consisting of an official fixed exchange rate and a market-based exchange rate regime. The official fixed exchange rate system was mainly used by the government, whereas the relatively market-based exchange rate system was used by importers and exporters in swap markets (Morrison and Labonte, 2013). In this first phase, the government had an objective of promoting domestic production by limiting imports. This was done by imposing restrictions on the amount of trade in foreign exchange, thereby limiting the excess to the foreign exchange market. This in turn resulted in a large black market for foreign exchange. Furthermore, the two exchange rates differed significantly. In 1993 the official exchange rate to the dollar was 5.77 versus 8.70 in the swap markets. Consequently, China's dual-exchange rate regime was criticized by several of their trading partners, especially the U.S., due to the restrictions it placed on foreign imports (Morrison and Labonte, 2013).

In the second phase, starting in 1994, the Chinese government unified the two exchange rate regimes, which marked the beginning of a market-based managed float regime. When the regimes were unified the Chinese government pegged the renminbi to the U.S. dollar at an

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[15]An import substitution industrialization strategy is a trade and economic policy that aims to replace foreign imports with domestic production.

initial rate of 8.28, which can be classified as a strong depreciation compared to the previous foreign exchange swap market rate (Morrison and Labonte, 2013). The depreciation had a stimulating effect on exports, contributing to a growing current account. The exchange rate was furthermore kept relatively constant until 2005, and the daily movements of the renminbi were limited to ±0.3 percent (Gang, 2008).

The peg was largely intended to promote a relatively stable environment for foreign trade and investment in China. The renminbi became largely convertible on a current account basis, however, not on a capital account basis. This implies that foreign exchange in China was not easily obtained for investment purposes. Overseas investments by Chinese citizen were highly regulated and restricted by the government. By limiting the capital outflow from China the government was able to retain more control over the renminbi and hence prevent excessive appreciation and instabilities to occur. (Morrison and Labonte, 2013)

The pegged regime worked well for the Chinese economy for several years, however, it had started to cause large internal and external imbalances in terms of a large and growing current account surplus (see graph 1 for illustration). Due to these imbalances, China was faced with an increased pressure from their trading partners to adapt a more free-floating exchange rate regime and let the renminbi appreciate. In the third phase, starting in 2005, China modified their currency policy and adapted a managed float regime with reference to a basket of currencies.[16] The basked consist of currencies of China's major trading partners, while the weightage of each currency reflects the geographical distribution of trade, services, or capital flows (Gang, 2008). Furthermore, the renminbi would now be adjusted based on the market supply and demand with reference to exchange rate movements of the currencies in the basket. In addition, the exchange rate of renminbi against the U.S. dollar was adjusted to appreciate from 8.28 to 8.11. However, in contrast to a free floating regime, the renminbi was only allowed to fluctuate by up to ±0.3 percent on a daily basis against the basket.

Since the renminbi was unpegged in 2005 the Chinese government has had a goal of increasing the flexibility of the exchange rate. The daily trading band of the renminbi has gradually been increased from ±0.3 percent in 2005 to ±0.5 percent in 2007 and ±1.0

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[16] U.S. dollar, Euro, Japanese Yen, Korean Won, as well as currencies of other countries such as Singapore, UK, Malaysia, Russia, Australia, Thailand and Canada.

percent in 2012 (Wei, 2014). Today, in 2014 the bandwidth is sat to $\pm$ 2 percent. Over the past decade the renminbi has appreciated against the dollar, slowly and gradually (see graph 1 for illustration). From 2005 to 2008 the USD/renminbi rate went from 8.11 to 6.83, and from 6.83 in 2008 to about 6.14 in November 2014. Along the way the renminbi, has however, had periods with depreciation, for instance during the global financial crises. This was, however, done in an attempt to stimulate and stabilize the economy, as a response to falling exports (Morrison and Labonte, 2008).
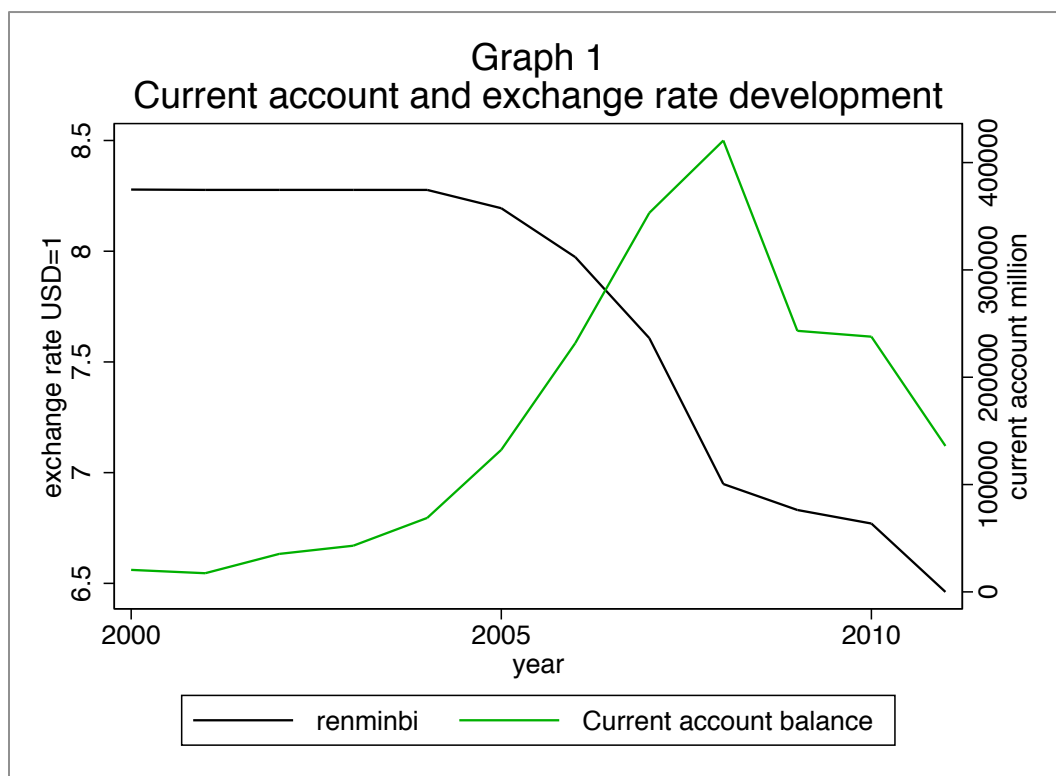
Source: Federal Reserve Bank of St. Louise, 2014

In order to have a stable and somewhat flexible exchange rate, China has been forced to have strong capital controls and constant market interventions in the foreign exchange market. This result can be directly derived from the impossible trinity framework presented in the previous section. In the next section the implications of the Chinese capital controls and foreign exchange market interventions are discussed in more detail.

3.3 Capital controls and foreign exchange interventions

In order to maintain stability in the economy and the exchange rate, the Chinese government actively intervenes in the foreign exchange market. When Chinese exporters receive foreign currency in exchange for their goods, China's central bank intervenes by purchasing the foreign currency-revenues at the prevailing exchange rate. In exchange the exporters receive either domestic currency or domestic bonds. Initially, the result of such an intervention is an increase in both foreign exchange reserves and monetary supply. However, in order to keep the monetary base unchanged, the Chinese central bank sterilizes these interventions by conduction contractionary monetary policy, such as selling government securities (Canales-Kriljenko, Guimaraes & Karacadag, 2003). A sterilized intervention will in turn extract the excess supply of renminbi and bring the monetary base back to its initial levels. As a net affect there is only an increase in the foreign exchange reserves and the Chinese government retains control over the domestic inflation by keeping monetary base unchanged.

Moreover, the Chinese government maintains several restrictions on its external sector[17]. Among other, China operates with a capital account that is effectively closed, which means that domestic citizens and institutions cannot move money in or out of the country, except in accordance to strict rules and regulations (Chang et al., 2014). For instance, Chinese individuals are not allowed to move more than $ 50,000 per year out of the country. Moreover, Chinese companies may only exchange renminbi for foreign currencies for approved business purposes, such as paying for imports or approved foreign investments. Due to these strict restrictions on capital outflows Chinese exporters and citizens in general have little intensive to hold foreign currency.

China's capital controls and market interventions can be discussed from two different viewpoints (Cheung et al., 2013). The first is that the capital controls are necessary in terms of having an independent monetary policy and a stable exchange rate. The only way this can be achieved is by giving up financial integration with the global economy, which China to some extend have done in the past few decades. Furthermore, it can be argued that it has been necessary to conduct market interventions in terms of retaining stability in the Chinese

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[17] The sector that interacts with the economies of other countries

economy. The contractionary monetary policy has been effective in controlling inflationary pressure caused by the large capital inflows. Consequently, the appreciation of the renminbi has been successfully limited. In terms of trade and employment, China has argued that it has been important to avoid sharp and massive fluctuations of the renminbi exchange rate. Furthermore, it has been argued that a gradual appreciation is important in terms of limiting renminbi speculations and inflows of "hot money", which could also be a destabilizing factor for the China's economy.[18]

The second viewpoint is that the capital controls and market interventions allows China to maintain an undervalued currency in order to provide cheap capital to fuel its remarkable economic growth. Oliver Jeanne (2012) for instance, argues that capital account policies could be designed to implement trade protectionism. Furthermore, an undervalued currency has the same affect on the economy as an export subsidy, which means that it gives China an unfair completive advantage in global trade. The Chinese restrictions on capital flows do not only create distortions in domestic capital markets but also induce imbalances in the global economy.

There is no doubt that the Chinese exchange rate policy and capital controls have contributed in creating global imbalances. In the next section there will, however, in addition be a discussion of other plausible reasons for the large and growing Chinese current account surpluses.

3.4 China's role in the global imbalances

According to trade theory, a fast growing country such as China should run a trade deficit, while "slow growing" U.S. should run a surplus. However, this is not the case. The cause of the build up of the Chinese current account surplus has been a matter of international economic policy debate for several years, especially the bilateral imbalances with the U.S.. The large current account surplus of China has been blamed for many of the problems faced by the U.S. economy, including closing of factories, growing trade deficit and even the asset bubble that caused the financial crisis in 2008 (Morrison and Labonte, 2008). The alleged

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[18] Hot money flows are referred to capital flows moving to countries with higher interest rates and /or expected changes in exchange rates.

Chinese currency manipulation has been at the epicenter of this debate. In this section, these arguments and other compelling arguments for the Chinese current account surplus will be presented.

One line of arguments explains the global imbalances through the high domestic savings rate and the correspondingly low consumption rate. China's aggregate savings rate has been the highest in the world for several years ranging at about 50 percent of GDP, which is considerably higher than the world average of 20 percent (Moneta, 2010) (The World Bank) (see box 3 for explanations of the high savings rate).

Box 3. Explanation of the Chinese savings rate

Many economists explain the high savings rate by cultural factors in East Asia and the underdeveloped social welfare system in the country. The Chinese history is dominated by war and high degree of social and economic uncertainty, explaining the strong preference for saving from a cautionary perspective. Economists also argue that the high savings rate has been caused by the family planning and one child policy since the 1970´s. Traditionally, Children have been viewed as a form of "life insurance" in china, taking care of the elderly when they grow up, however, the family planning has resulted in a demographic gap in China, reducing the youth dependency ratio. Mao and Zhou (2009) find that a 20% decline in the youth dependency ratio has been associated with a rise of China's net foreign asset position by 90% of GDP.

Consequently, due to the low consumption rate the Chinese production has exceeded domestic consumption, and surplus capacity has been exported to foreign countries in order to maintain domestic employment (Corden, 2009). As a result, China has been running a large trade surplus for several years, especially with the U.S.. Furthermore, scholars explain China's large trade surplus by their role as a final point of assembly in the supply chain for multinational corporations. They argue that the growth of the Chinese trade imbalance with the U.S. has gone hand in hand with a reduction of U.S.' imbalance with other Asian economies (Morrison and Labonte, 2013). Multinational corporations have been importing raw material and intermediate goods from other Asian countries to China, which then has bee assembled in China and sold to the U.S..

The natural market response to such persistent trade surpluses would be an appreciation of the renminbi because of high foreign demand for Chinese exports and hence the Chinese currency. However, such an appreciation would weaken Chinese competitiveness compared to other Asian economies. In order to keep Chinese exports competitive in the global market, it has been argued that the central bank of China has actively intervened in the foreign exchange market. As explained in the previous section, China has limited an appreciation of the renminbi by extracting the large dollar trade surpluses from the economy and sterilized these interventions in order to control inflation as well.

Such an exchange rate policy has left China with large foreign currency reserves, especially U.S. dollars. To accumulate interest payments on these reserves at low risk, China has been purchasing U.S. Treasury Securities. In that manner, savings has been channeled away from local uses and into international capital markets. This is what Bernanke refers to as the "global saving glut", and has been argued to be one of the key drivers behind the global imbalances found in the world today (Bernanke, 2005).

Beside the Chinese exchange rate policy, there are also other factors that have contributed in maintaining the Chinese exports competitive, and hence contributed to the large current account surplus. Huang and Tao (2010) find a clear correlation between the build up of the current account surplus since 2000 and growing factor price distortions in the Chinese economy. The factor price distortion has been caused by the gradual and asymmetric market liberalization of the Chinese economy. While goods markets are almost fully liberalized – factor markets, including labor, capital and raw material markets, remain heavily distorted. The factor price distortions have effectively been working as producer subsidies. This in turn has artificially raised the profitability of production, increased investment returns and improved the competitiveness of Chinese exports. In addition, the indirect subsidizing of producers has suppressed the share of household income in GDP and hence the share of GDP devoted to domestic consumption, further adding to the external imbalances.

The discussion presented illustrates that the bilateral imbalance between the U.S. and China cannot solely be explained through the Chinese exchange rate policies. In the policy debates addressing the global imbalances the focus has, however, been on the role of an alleged Chinese renminbi undervaluation. As the literature review in the following section illustrates; whether or not the renminbi can be considered misaligned, is now more uncertain than ever.

3.5 Literature review

Up until 2010 most estimates of the Chinese currency misalignment presented a considerable underestimation of the renminbi (see for instance, Cline and Williamson (2010), Subramanian (2010), Bergsten (2010) and Cheung et al. (2010)). However, this has changed in line with China's new currency regime and whether the renminbi can be designated as undervalued is now strongly debated.

At the point of writing, the most resent Fundamental Equilibrium Exchange Rate (FEER) estimate of China's currency misalignment is from May 2014, by Cline and Williamson. The authors find that the renminbi is at its FEER level, meaning that there is no need for adjustment to reduce excessive external imbalances (Cline, 2014). The corresponding estimated undervaluation against the U.S. from 2011 is 28.5 percent, suggesting a considerable correction of the renminbi in the past three years (Cline et al., 2011). The calculations are based on a norm of fundamental equilibrium of a current account imbalance of ± 3 percent of GDP.

The IMF Consultative Group on exchange rates publishes an estimate of the renminbi misalignment once a year based on three different currency models. They find that the Chinese currency undervaluation ranges from 3 to 23 percent in 2011 (IMF, 2011). The misalignment in 2012 is, however, considered to be negligible (Morrison and Labonte, 2013).

In a BEER model with five explanatory variables Cui (2013) examines the currency misalignment of the renminbi with monthly data over the period from 1997 to 2012. The author finds that the renminbi undervaluation ranges from 25 to 35 percent during the course of 2011 alone. This illustrates how sensitive the misalignment is to the point of estimation.

Zhang and Chen (2014) find that the renminbi is undervalued by 38 percent in 2011 according to a log linear Penn effect model.[19] However, if a control variable for net financial assets is included, the misalignment of the renminbi turns from being undervalued, to becoming overvalued by 8 percent.

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[19] The Penn effect is estimated on a panel of the 19 biggest economies of the world in terms of 2012 GDP, from 1980 to 2012.

Kessler and Subramanian (2014) study the Chinese currency misalignment with a cross-country Penn effect regression on the most resent ICP benchmark data from 2011. The authors estimate the Penn effect with a quadratic and a linear regression specification for two different samples. Sample number one exclude oil-exporting nations, whereas sample number two excludes countries with a population less than one million. For the linear regression, the renminbi is undervalued by about 10 percent, taking the average undervaluation of the sample. For the quadratic specification the renminbi is overvalued by 2.7 percent and 10 percent, for sample one and two respectively. Since the estimated magnitude of the misalignment is small, the authors conclude that renminbi is now fairly valued.

As it follows from the literature review, there is no consensus among the scholars of whether the renminbi is over- or undervalued. In the following section this thesis contributes to the current discussion by assessing the real renminbi misalignment in light of a novel specification of the Penn effect model.

4. Analysis

In this section an assessment of the real renminbi misalignment will be explored by estimating the Penn effect on the 2011 ICP data set. First, we provided definitions of key components of the analysis and a description of the data. Second, the functional form of the Penn effect is investigated by running and comparing three different regressions; a linear, a non-linear and a dummy regression allowing for different intercept and slope between OECD and non-OCED countries. The last part of this section presents the misalignment of the real renminbi, which is estimated based on the Penn effect regression that best describes the data.

4.1 Data and definitions

All data is collected from the 2011 ICP for international comparison of income and price levels. The PPPs reported in the ICP are based on price surveys, whereas the GDPs and expenditure data is drawn from countries' national accounts. The exchange rates implemented in the ICP are annual average rates drawn from the international financial statistics of the IMF.

In this analysis the U.S. is used as the benchmark country. The choice of a bilateral analysis with the U.S. is motivated by comparability with previous studies and the fact that the U.S. is China's main trading partner. Moreover, to construct price levels, this analysis implement the ICP reported PPPs and exchange rates (USD=1) to construct a proxy for the bilateral exchange rates with the U.S. (recall the relation from Eq. 6).

4.2 Establishing the Penn effect

The functional form of the Penn effect has rarely been discussed. Most scholars have estimated the relation as a log-linear regression function over a full sample of countries. However, for the 2011 ICP data, it is not apparent that the relationship between income and price level is best approximated with a linear regression function (see Graph 2).

Graph 2
All observations
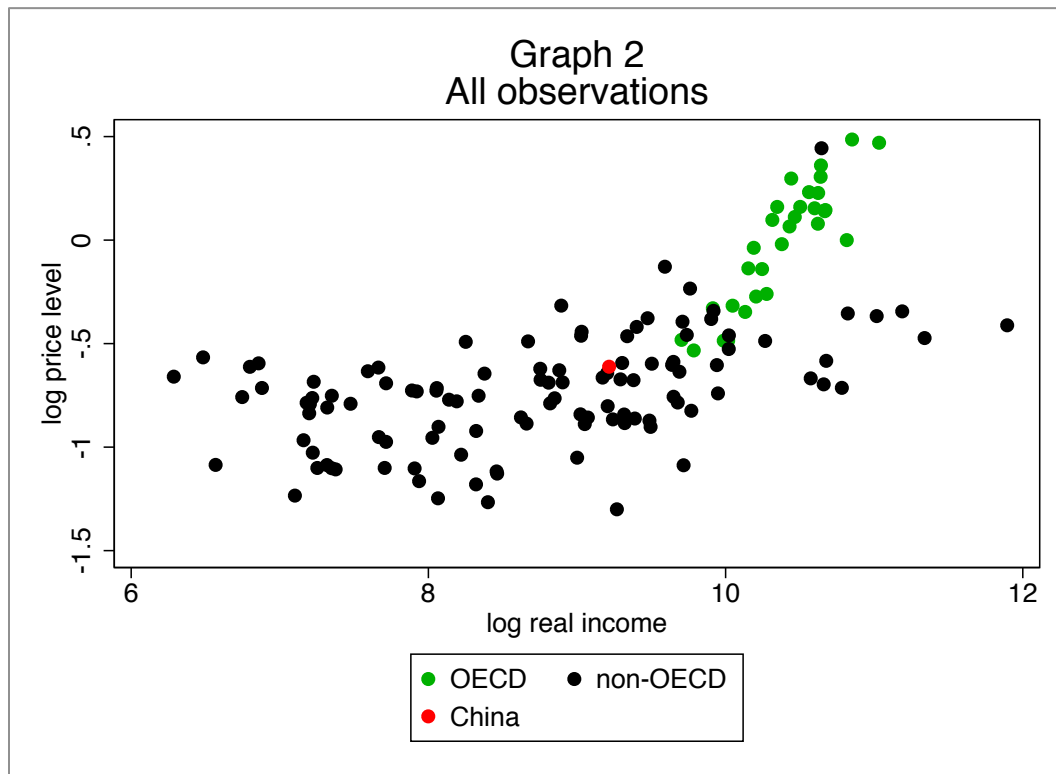
Some scholars have pointed out differences in the Penn effect between low- and high-income countries as a possible explanation for why a linear regression fits poorly (See among others Rogoff (1996), Coudert and Couharde (2005) and (Hassan, 2012)). For instance, Rogoff (1996) argues that the Penn effect over a full data set is strong, but less so when low-income countries are examined separately. What is especially interesting with the 2011 ICP data is, however, the clear separation of price levels within the group of high-income countries.[20] This separation seems to be between OECD and non-OECD countries.

To establish the functional form that best describes the relationship between income and price level, three different regressions are run and compared. First, the conventional log-linear regression function over the full sample is specified. Second, a quadratic function and a lowess regression is run to allow for a non-linear relation between income and price levels. Last, a dummy regression is presented, which allows for different intercept and slope coefficients between OECD and non-OECD countries. The regressions are then compared and discussed theoretically.

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[20] There is a clear separation of the cluster between countries with an income above natural log of real income of 10, which is about the real income of Hungary.

4.2.1 Regression analysis

In all the regressions, countries with a population of less than one million are excluded. This is to reduce price bias from small island societies with inflated price levels due to tourism and high transportation costs. Zimbabwe and Uzbekistan are also removed, since they are clear outliers.[21] Consequently, the regressions are based on a total of 141 observations.[22]

Moreover, all regressions are run on two samples; sample one including all observations and sample two excluding highly oil dependent economies.[23] Oil dependent countries have in some studies shown to follow different real exchange rate adjustments than predicted by the Penn effect and are for that reason removed from sample number two.[24] Additionally, comparative price levels in oil dependent countries are generally believed to be higher.

The explained variable in the Penn effect regression is the price level, PL_i, for country i, as defined in Eq. 6. The explanatory variable, $GDPP_i$, is the expenditure based gross domestic product (GDP) per capita in PPP terms relative to the U.S. The GDP per capita is from now on referred to as real income. The coefficient, β, is referred to as the *"Penn effect"* and represents the expected change in a countries price level when income changes with one percent. ε_i is an error term representing the difference between country i's observed price level and the fitted value.

First, the Penn effect is estimated in the conventional way as a log-linear regression (natural logarithms). The log-linear Penn effect is captured by the following equation:

$$(13) \qquad \log(PL_i) = \alpha + \beta \log(GDPP_i) + \varepsilon_i$$

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[21] Zimbabwe experienced hyperinflation in 2008-2009 and the government of Zimbabwe stopped filing official inflation statistics. Uzbekistan has experienced strict capital controls and lack of currency convertibility.
[22] List of all observations is found in appendix.
23 Highly oil dependent countries are defined as top 15 net oil exporters as off 2012. The list is of countries is collected from U.S. energy information administration, EIA.
[24] For discussion, see Appendix 5.

Second, a quadratic regression function and a lowess estimation are specified to allow for a non-linear relation between income and price levels.[25] The quadratic function is specified as follows:

$$(14) \qquad \log(PL_i) = \alpha + \beta \log(GDPP_i) + \partial \log (GDPP_i)^2 + \varepsilon_i$$

The lowess regression is run to impose minimal restrictions on the functional form of the Penn effect. The lowess regression uses a weighting procedure where the points in the samples are assigned weights according to their distance from the central point $(PL_i, GDPP_i)$ of the scatter. The weights can be adjusted by setting the bandwidth of the regression. In this analysis a STATA default of 0,8 is used (meaning that the regression uses 80 percent of the observations closest to the central point).

Last, a dummy regression allowing for a different Penn effect between OECD and non-OECD countries is specified. The dummy variable, D, takes the value of one for OECD countries, and zero for non-OECD countries. The regression is as illustrated in the following equation:

$$(15) \qquad \log(PL_i) = \alpha + \beta \log(GDPP_i) + \theta D + \partial \log (GDPP_i * D) + \varepsilon_i$$

According to the Penn effect regressions, the misalignment of country i's price level and implicitly the real exchange rate is the difference between the actual price level (as reported in ICP), PL_i, and the price level, $\widehat{PL_i}$, predicted by the Penn effect regression.

$$(16) \qquad Misalignment = (PL_i - \widehat{PL_i})$$

The percentage misalignment is defined as follows:

$$(17) \qquad \% \, Misalignment = \frac{PL_i}{\widehat{PL_i}} - 1$$

In this analysis, a country with a Penn predicted price level higher than the reported ICP level, $(\widehat{PL_i} > PL_i)$, is considered to have an *undervalued* real exchange rate. Conversely, a country with a Penn predicted price level lower than its corresponding ICP price level,

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[25] Hassan (2012) finds robust evidence for a non-linear Penn effect, both in a cross section and panel dimension.

$\left(\widehat{PL_\iota} < PL_i\right)$, is considered to have an *overvalued* real exchange rate.

The regression results are presented in table 1. For the linear specifications, only the regression on sample 1, including all observations, is presented. This is due to the negligible difference in the estimated coefficients between the two samples.[26]

Table 1				
	Linear: *Sample 1*	**Quadratic:** *Sample 1*	**Quadratic:** *Sample 2*	**Dummy:** *Sample 1*
Log real income	0.216***	-1.030***	-1.755***	0.110***
Squared log of real income		0.0697***	0.112***	
OECD Dummy				-6.754***
Interaction Dummy				0.703***
Constant term	-2.539***	2.916*	5.935***	-1.691***
R^2	0.451	0.529	0.640	0.717
Observations	141	141	126	141
Table 1: Regression results the Penn effect Sample 1: Including all countries; Sample 2: Except highly oil-dependent economies. * significant at 5%; ** significant at 1%				

All the slope coefficients are statistically significant at a one percent confidence level. The regression fit does, however, differ considerably between the functional forms. The standard log-linear regression, over the full sample, poorly describes the relation between income and price levels with the lowest R^2 of 0.451. The fit of the quadratic specification improves notably between the two samples, where sample two, without the top oil exporters, gives a clearly better fit than sample one, including all countries. It is, however, clear that the regression fit of the dummy specification is superior to the other functional form specifications with an R^2 of 0.717. The coefficient on the interaction dummy is statistically

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[26] The non-linear regressions and the linear regression are presented graphically in the appendix (section A4). The dummy regression is presented graphically in section 4.3.

significant at a one percent significance level, *providing evidence that the Penn effect is different in OECD and non-OECD countries*. Furthermore, the Penn effect is estimated to be much stronger for OECD countries, than non-OECD countries. An explanation of the differences in the Penn effects between the two groups of countries will be provided in the following section.

4.2.2 Theoretical explanation

The explanation of the difference in the Penn effect between OECD and non-OECD countries should rest on the basic assumptions driving the Penn effect.

As previously noted, the Penn effect, in the explanation provided by Balassa and Samuelson, relies on wage increases in non-tradable sector following productivity growth in tradable sector. However, if productivity in tradable sector does not fully translate into higher prices in non-tradable sector, the Penn effect will be weaker.

At least two factors can mitigate the price increase in non-tradable sector. First of all, if the productivity growth in non-tradable sector is relatively higher or the same as in tradable sector, price levels will not increase. Secondly, imperfect labor mobility across sectors can mitigate the predicted wage increase in non-tradable sector, which initially is the driver behind the increase in price levels. In this respect, the lower Penn effect in non-OECD countries can be explained through either high productivity growth in non-tradable sector than tradable sector or imperfect labor mobility across sectors.

Hassan (2012) presents a productivity-based explanation for differences in Penn effects across countries. He propose that the Penn effect may be lower for developing countries due to high productivity growth in agricultural sector, which mitigates the price increase in non-tradable sector.[27] The rationale is that at earlier stages of development, the productivity growth is dominated by the agricultural sector. This causes a reduction of the relative price of agricultural goods, which are mostly non-traded goods for developing countries.[28] This reduction of prices in agricultural sector works against the Balassa-Samuelson predicted

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[27] Hassan (2012) defines developing countries as countries with incomes below the World bank high-income threshold.

[28] Fao reports show that in year 2000, 70% of arable land in 159 countries was staple food crops and with the exception of some countries almost all was for domestic consumption (Hassan, 2012)

price increase of non-tradable goods relative to tradable goods. Consequently, the greater the share agriculture is of total output (GDP), the lower will the Penn effect be.

This is an appealing argument for explaining the lower Penn effect for low-income countries. However, the rationale fails to describe the difference in the Penn effect between high-income OECD and non-OECD countries. Agriculture represents a minimal share of total production and expenditure in high-income non-OECD countries (see box 4 for list of countries). Furthermore, the sectorial composition of these countries in terms of the share of services and agriculture of total output (GDP) is similar to the OECD countries in the sample (World Bank data).

Box 4. High-income non-OECD countries

High-income non-OECD countries are defined according to the separation of the cluster illustrated in graph 2. The list of high-income non-OECD countries is as follows:

Country	Real income (USD)
United Arab Emirates	60,886
Bahrain	43,360
Oman	42,619
Saudi Arabia	48,163
Singapore	72,296
Hong Kong SAR, China	50,129
Kuwait	84,058
Taiwan, China	39,059
Qatar	146,521

Some of these countries are highly oil dependent economies. Taiwan, Hong Kong and Singapore are all financial hubs in Asia. Furthermore, all the countries are classified as developing countries according to the UN Developing Program (UNDP), due to comparatively low life expectancy and educational index score.

A more plausible line of argument rests on the notion of differences in labor mobility between high-income OECD and non-OECD countries. The existence of wage differentials and limited labor mobility between tradable and non-tradable sector has been supported in previous literature (See amongst others Lee (2005), Schmillen and Ferris (1996)). For

instance, a recent study by Cardi and Restout (2013) finds that the wage increase in non-tradable sector is positively correlated with the degree of labor-mobility.[29] If wages to a larger extent fails to equalize across sectors in high-income non-OECD countries, this can explain the difference in price levels between high-income OECD and non-OECD countries.

A core value of the OECD is an open and transparent market economy, with a strong democracy. Principles that can be believed to be associated with higher factor mobility. These principles, however, may not be established to the same extent in the high-income non-OECD countries. Furthermore, educational equality across sectors is believed to be an important driving factor for labor mobility between tradable and non-tradable sector. The educational levels tend to be higher for tradable sector than non-tradable sector (see for instance Jensen et al. (2005)).[30] Educational inequality can make it difficult for low-educated and –skilled works from non-tradable sector to work in the tradable sector. Wages hence fail to equalize, mitigating the predicted price level increase.

In the OECD countries, equality in education is an important fundamental value. The OECD works to ensure that the population holds equal skills in order to enhance productivity (OECD, 2014). It seems reasonable to assume, however, that this value is not as strongly embedded in the high-income non-OECD countries. Although it is difficult to obtain data on educational distribution, a review of the data of mean years of education at least supports the differences in educational levels between high-income OECD and non-OECD countries in the sample.

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[29] Labor mobility is approximated by calculating the ratio of the absolute change in sectorial employment resulting from labor reallocation to average employment over 2 years.

[30] For the US, Jensen et al (2005) find that difference in years of education can explain about 50% of the wage difference between tradable and non-traded sector.

Graph 3
Mean education
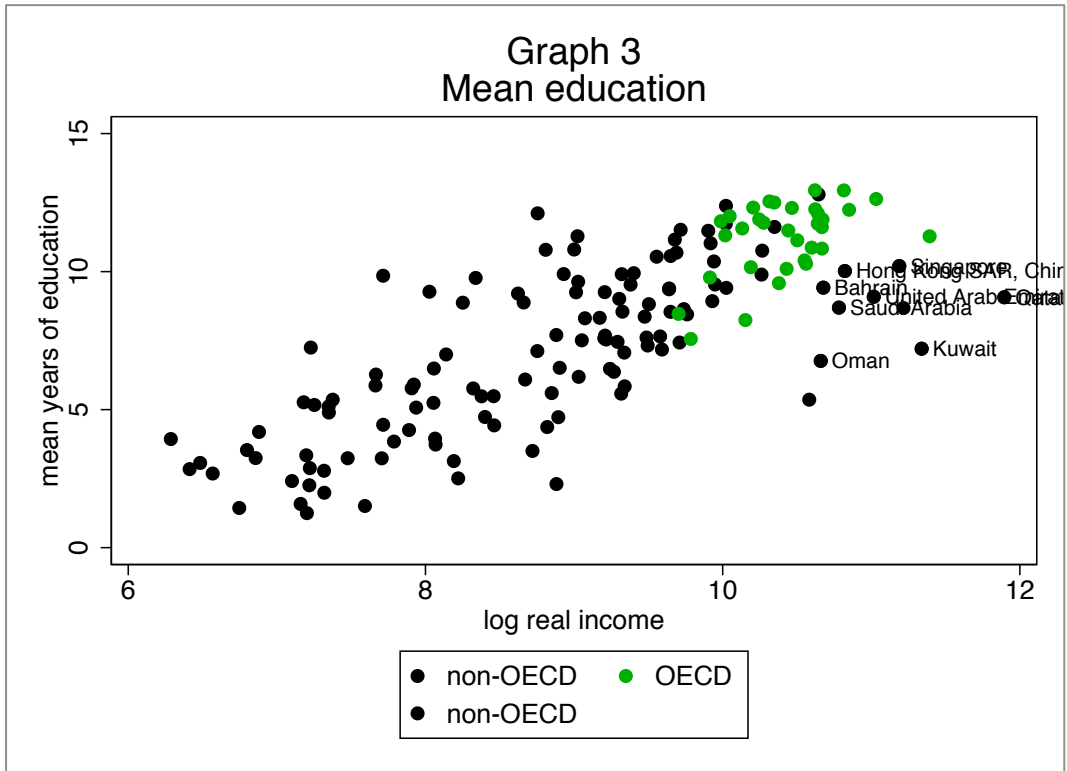
The similarity with the pattern of the Penn effect is quite striking. In terms of mean years of education, non-OECD countries with high-income levels and low price levels, have systematically lower mean years than the high-income OECD countries. If the lower mean years of education in non-OECD countries can be associated with higher educational inequality and labor immobility between sectors, then it supports the differences in the Penn effect between high-income OECD and non-OECD countries.

4.3 Findings

Taking the strong empirical relation, and the plausible theoretical explanation into account, it is concluded that the dummy regression over OECD and non-OECD countries best approximates the relationship between price levels and real income in the 2011 ICP data. Now that the functional form of the Penn effect is established, the real renminbi misalignment can be estimated. The dummy regression result is presented in graph 4.
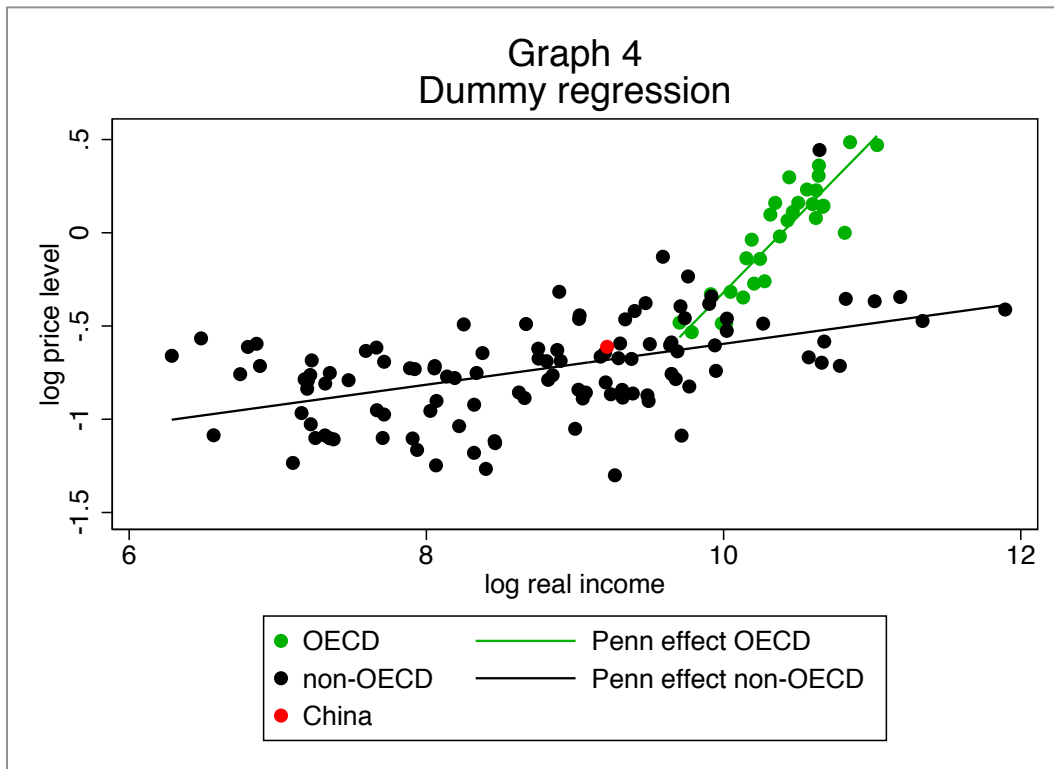
China and the other countries in the sample are plotted against the estimated Penn effect regression. The real exchange rates of all countries outside of the regression line are considered misaligned and are expected to converge towards the line in the long run. The real exchange rates of all countries with price levels below the regression line are considered undervalued. Conversely, the real exchange rates of countries with price levels above the regression line are considered overvalued.[31] The further away from the estimated regression, the more misaligned are the countries' real exchange rates.

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[31] Recall that the price level equals the real exchange rata. In that respect, an undervalued price level means higher competitiveness of the country in world trade.

It is apparent from the graph that China's price level is located just above the regression line. At this point the estimated overvaluation of the renminbi is 6.7 percent. The misalignment is not statistically significant at a 5 percent confidence interval, which means that *the real renminbi can no longer be considered misaligned compared to the U.S. dollar*.

It is interesting to view the result in light of similar studies done on the renminbi misalignment for the same period. At the point of writing, only one article has been published applying the Penn effect model on the 2011 ICP data. As presented in the literature review, the article by Kessler and Subramanian (2014) find a result that is broadly in line with the fining of this thesis. The authors, however, do not make the distinction between OECD and non-OECD countries as in this thesis. Moreover, the authors estimate the misalignment as the deviation from a quadratic and a log-linear Penn effect. The log-linear and quadratic regressions conducted in this analysis provide similar misalignment results, however, they provide a poorer fit for the data compared to the dummy regression.[32]

By applying purchasing power parity based approaches, Zhang and Chen (2014) and Ciu and Wang (2013) all find that the renminbi is considerably undervalued for the year 2011.[33] These scholars estimate the Penn effect over a panel of data, with 2012 as the most recent year. As it follows, these results are in strong contrast of those found in this thesis. Models estimating currency misalignments on panel data may yield different results due to severe measurement errors in the price levels (Johnson et al., 2009). This may be one explanation for the noticeably difference from our result. Furthermore, the scholars specify the Penn effect model as a linear regression function over both OECD and non-OECD countries. As we have illustrated in this thesis, OECD and non-OECD countries follow different price level patterns; hence their result may be misleading. These differences, may explain part of the discrepancies between their result and the one presented in this thesis.

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[32] Kessler and Subramanian (2014) exclude oil dependent countries from the regression. See also the appendix for a discussion on the exclusion of this group of countries.
[33] Zhang and Chen (2014) use the Penn effect model and Ciu and Wang (2013) use a BEER model.

5. Robustness

The results presented in the analysis, and the results of many other models of currency misalignment, are highly sensitive to measurement errors in the data. In the following sections, we explore the robustness of the results to different sources of measurement errors. The first part of this section elaborates in detail on the sources of and problems associated with measurement errors in the PPPs. Secondly, we propose a method to correct for biased price levels and real incomes through the Engel curve. The misalignment of the renminbi is then explored in light of these new "Engel corrected" price levels.[34] Lastly, we present a brief discussion on possible biases associated with the nominal incomes and exchange rates.

5.1 Robustness of the PPPs

The most severe measurement errors and biases in the Penn effect regressions are associated with the PPPs.[35] PPPs are important ingredients in all models of currency misalignment, hence it is important to elaborate on some of the intrinsic flaws of the price data available for international comparisons.[36] The sources of bias in the Penn effect regression can both stem from the variance of the measurement errors and the mean of the measurement errors of the PPPs.

5.1.1 Bias from the variance of measurement error

The variance of measurement error in the PPPs can cause biased and inconsistent estimates of the Penn effect (Chen et al., 2007). One of the assumptions for consistent and unbiased estimates for an Ordinary Least Square regression (OLS) is that the independent variable is uncorrelated with the error term. In the Penn effect regression, however, this is not the case since the PPPs enter in both the explained and explanatory variable. Furthermore, the biases tend to underestimate the Penn effect and can even become negative for sufficiently high variances of the measurement errors.[37]

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[34] Engel corrected price levels refer to the new price levels calculated based on the Engel procedure presented in this Thesis.
[35] The reader is reminded of the definition of price level $PL = PPP/E$.
[36] It is here referred to the ICP and the PWT. See box 2 in the theory section for a presentation of the datasets.
[37] See appendix 7 for calculations.

The variance of the measurement errors has been presented to be larger when the Penn effect regression is applied on time series data from the PWT. Johnson et al. (2009) find that data revisions between PWT versions are substantial and systematic. The further the data is from the benchmark year in the PWT, the more likely is the data to be revised between versions of the PWT. Furthermore, the variability is systematically larger for small countries and for countries with a lower statistical quality grade.[38] The quality grade is correlated with income; hence the variance of the measurement errors is systematically higher for low-income countries.

The problem of increased variance in the measurement errors over time is inherited to the methodology of price and income extrapolation for non-benchmark years. The price level extrapolations in the PWTs are based on an assumption that the countries have equal structure and are evolving similarly over time. However, this is clearly not the case for developing countries when compared to the U.S (International Comparison Program, 2014). For instance, it is well known and documented that some elements of consumption are highly elastic to income. This means that as income increases the composition of a country's representative basket of goods will tend to change.

In this paper, the Penn effect has been estimated on benchmark year and countries of the 2011 ICP data to reduce bias caused by the variance of measurement errors. However, there are also several sources of bias caused by the mean of measurement errors. This will be discussed in the next section.

5.1.2 Bias from the means of measurement error

The main sources of PPP bias from the mean of measurement errors are the methods of aggregation, goods comparability and representability, and geographical representability.

First of all, the method of aggregating the PPPs in the ICP tends to undervalue the price level of low-income countries. The PPPs are computed using the Geary-Khamis (GK) method of aggregation. This methodology gives countries with a larger physical volume of consumption a greater weight in the construction of the composite world price. Implicitly, the international prices that are used to evaluate consumption in all countries will be closer

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[38] In the PWT all countries are graded after the quality of their statistics.

to the rich countries' prices. This can cause an undervaluation of the price level of low-income countries that generally have lower volumes of consumption.

Second, it is impossible to make the list of goods, which is used to construct the PPPs, fully comparable and representative across countries (International Comparison Program, 2014). The ICP price calculations are based on different good categories called basic headings. Each basic heading consists of a long list of products, which is drawn on the principle of comparability (the products are comparable across countries) and representativeness (the products are representative for the consumption bundle across countries).

Deaton and Heston (2010) highlights quality mismatch as a major source of bias in the PPPs when comparing goods across countries. It is difficult to account for quality differentials between goods of the same category when computing the PPPs. Take for instance meat. There excises several sorts of meat with different quality and price. If the high-income countries consume more of the high quality meat and the low-income countries consume more low quality meat, the price of meat in the low-income countries will be undervalued. As quality tend to be higher in high-income countries, quality mismatch will tend to lead to an underestimation of the price level of lower-income countries.

Problem with representativeness of products across countries may also create biased results. The bias may stem from either that an important product in the consumption bundle of a country is not part of the list, or that a product on the list cannot be found in a country. There may not be serious biases due to the representativeness issue if the non-representativeness is not systematic and is well distributed across countries (Diewert, 2008). Furthermore, Deaton and Heston (2010) examine the problem in the 2005 ICP by computing a Tornqvist index[39] to measure how different goods change the PPP index. For Africa and Asia they find evidence that the prices are systematically overstated due to the issue of representativeness. For the 2011 ICP, Qiu et al. (2014) however, find that the representativeness of the 2011 PPPs for China is reliable and hence does not bias the price levels.

Lastly, the ICP PPP estimates may not be representative for all areas within a country. For instance, Ravallion et al. (2007) find that there may exist sizable differences in prices between urban and rural areas in developing countries (including China). This implies that if

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[39] The Tornqvist index is a price or quantity index.

a developing country only participates in the price survey with urban areas, the PPPs may overstate the actual price level in the country.

5.1.3 The 2011 ICP round

It is difficult to assess how severe the problems discussed in the previous section are in the 2011 ICP data. Since the ICP 2011 round was first published in April 2014, little research has been published on the quality of the 2011 PPPs.

In the 2011 ICP round, there was a considerable downward revision in the price levels for developing countries from the 2005 ICP, and consequently a downward revision of the world inequality. Deaton and Aten (2014) argues that the 2011 ICP round represents an improvement from the 2005 round, thereby correcting some of the upward biased caused by the method of linking regions in the 2005 PPPs. Ravallion (2014), however, takes the opposite account and believes the 2011 PPPs are considerably undervalued. Ravallion (2014) argues that the observed drop in price levels of developing countries is not compatible with the economic growth experienced by these countries, referring to the dynamics of the Penn effect.

What surely can be considered as an improvement from the 2011 ICP is China's full participation. In the 2005 ICP round, China only participated with 11 out of 34 provinces, containing mostly capital cities and their surrounding areas (Asian Development Bank , 2014). Deaton and Heston (2010) found that this led to an overestimation of the Chinese PPPs of about 20 percent. However, in the 2011 ICP China participated with a total of 30 out of 34 provinces, both rural and urban areas.

Despite these improvements, the methodology of PPP is more suitable for highly homogenous market economies, which is surly not the case for China (Qiu, 2014). As one of the biggest countries in the world, China has significant differences in prices, consumption patterns and living standards within and between provinces. Furthermore, despite the fact that China has evolved towards becoming a market economy in the past decade, the country is still highly regulated. For that reason, prices of some products do not fully reflect their correct price levels. Consequently, it is hard to guarantee the representativeness of the Chinese price levels in the 2011 ICP (Qiu, 2014).

5.1.4 Price level and real income correction

The above discussion indicates that measurement errors in the PPPs are expected to underestimate the price level of low-income countries, due to the issues related to quality matching and the method of aggregation. The general tendency of undervaluation of the low-income countries' price levels can result in considerable biases in the estimated renminbi misalignment. The implications for the renminbi misalignment will be especially large if the bias in the PPP for China is of the opposite sign (overvalued). To try to examine the robustness of the misalignment result to measurement bias, a method of correcting the bias is presented by applying the strong empirical relation between food shares and real income.

The strong relation between food share and income has been named the "Engel's law" after the statistician Ernst Engel. Engel was the first to investigate the relationship between income and spending on food in 1857 (Chai & Moneta, 2010). The law states that there is a negative relationship between the budget share for food and real income, ceteris paribus. It is important to keep in mind that there is not an absolute decrease in food expenditure, but instead the law states that the households increase their food spending by less (in percentage) than their increase in total expenditure. In other words, since the income elasticity of food is low, the proportion of income spent on food decreases as income increases.

The existence of an Engel curve has been broadly supported in the literature and has been widely applied to measure bias in PPPs (see for instance Hamilton (2001), Costa (2001), Almaas (2012), Nakamura and Steinsson (2004)). By following a three-step procedure, the Engel curve can be implemented to estimate alternative price levels and real GDPs. The corrected income and price levels will be referred to as Engel corrected data.

Step one: Establishing the Engel relation
In the first step, the Engel curve is estimated by regressing the food share of total consumption expenditure on real income. To minimize measurement errors the Engel curve is estimated over all OECD countries in the sample.[40] It should be noted that this implicitly assumes that the food share of non-OECD countries follow the same law as OECD countries. This should not be a problematic assumption as previous research indicates that

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[40] According to the statistical capacity index of the World Bank, and the quality grade provided in the PWTs, data quality in OECD countries is generally believed to be good.

the Engel curve is robust across time and countries of different income groups (See Spivack and Pritchett, 2013 for an overview).[41]

The Engel curve is specified as follows:

$$(17) \qquad FS_i = \alpha + \beta \ln(GDPP_i) + \varepsilon_i$$

Where the food shares are obtained by the following equation:

$$(18) \qquad FS_i = \frac{Houshold\ food\ expenditure}{\sum Houshold\ expenditures}$$

The food share, FS_i, is defined as a household's food expenditure over the household's total consumption expenditure in country i.[42] The explanatory variable, $GDPP_i$, is the expenditure based gross domestic product (GDP) per capita in PPP terms relative to the U.S. The β coefficient gives the expected change in food shares as real income increase. ε_i is an error term representing the difference between country i's observed food share and the value predicted by the model.

Running the regression specified in equation (18), yields a slope coefficient of -0.1, statistically significant at a 1 percent confidence level. This is in line with previous researches (See Spivack and Pritchett, 2013 for an overview). Furthermore, as illustrated in graph 5, the relation between food shares and real incomes is strong. The regression line provides a good fit for the sample with a R^2 of 0.77. The predicted values of the slope and constant term are applied in later steps.

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[41] Furthermore, this thesis finds that result of the real renminbi misalignment is robust to inclusion off all countries in the Engel-curve.
[42] Drawn from the 2011 ICP d (Economic Research Division Federal Reserve Bank of St. Louise, 2014)ata.

Graph 5
Engel Curve
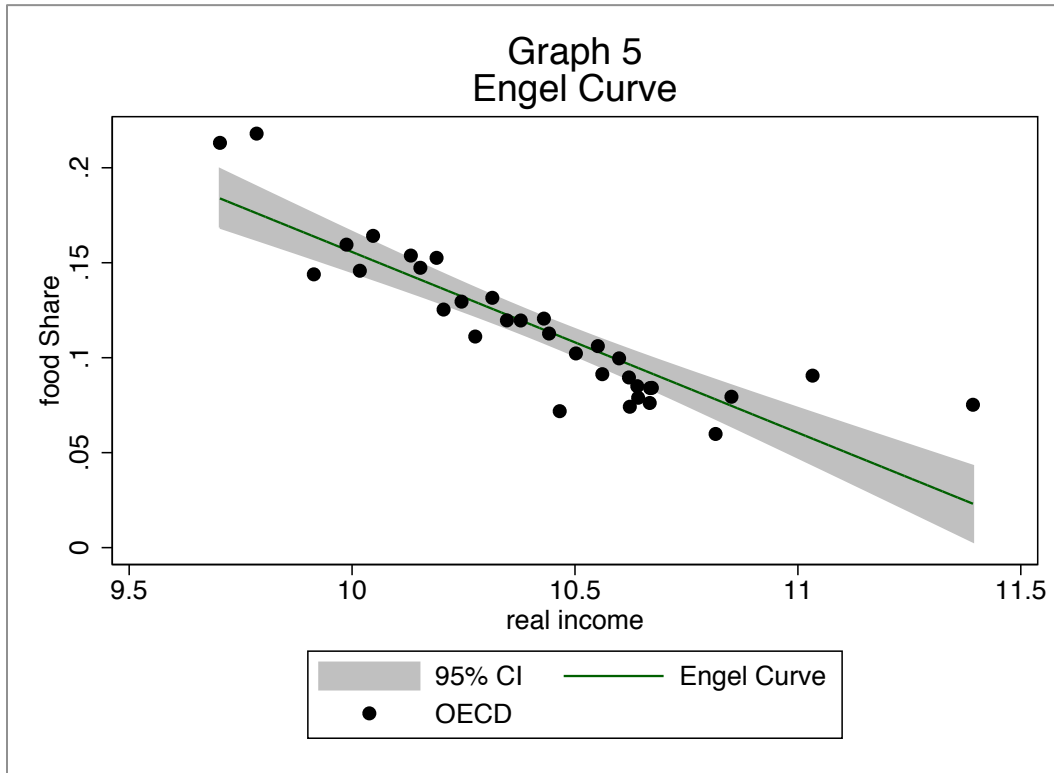
Step two: Correcting real income

In the second step, the real incomes corrected for price level bias are calculated. As illustrated in step one, the food shares from the ICP are calculated based on nominal incomes, hence, there is no price level bias in the food shares. Consequently, by applying the food shares (FS) reported in the ICP and the estimated slope and constant term from step one ($\hat{\alpha}$ and $\hat{\beta}$), the measurement errors from the price level is removed from real income.

The Engel curve is solved for the log of real income, yielding the following relation:

$$(19) \qquad \ln GDPP_i^{eng} = \frac{(FS_i - \hat{\alpha})}{\hat{\beta}}$$

Eq. 19 provides the price level corrected estimates of real income, $GDPP_i^{eng}$.

Step three: Correcting PPPs

In the third step, new price levels, PL_i, are calculated based on the Engel corrected real incomes, $GDPP_i^{eng}$, and the nominal incomes reported in ICP, $GDPP_i^{nom}$. As illustrated in Eq. 20, a country's price level equals the nominal income over real income. The price level is in that respect defined as the deflator of nominal income.

$$(20) \qquad PL_i^{eng} = \frac{GDPP_i^{nom}}{GDPP_i^{eng}}$$

The Engel corrected price levels are obtained by taking the logarithm of the relation in Eq. 20 and applying the Engel corrected real income as the denominator.[43]

$$(21) \qquad \ln\left(PL_i^{eng}\right) = \ln\left(\frac{GDPP_i^{nom}}{GDPP_i^{eng}}\right) = \ln(GDPP_i^{nom}) - \ln\left(GDPP_i^{eng}\right)$$

5.1.5 The Engel corrected data

Following the above procedure we obtain the corrected real incomes and price levels for all countries in the sample. The procedure yields considerable corrections of the ICP price level and real incomes.

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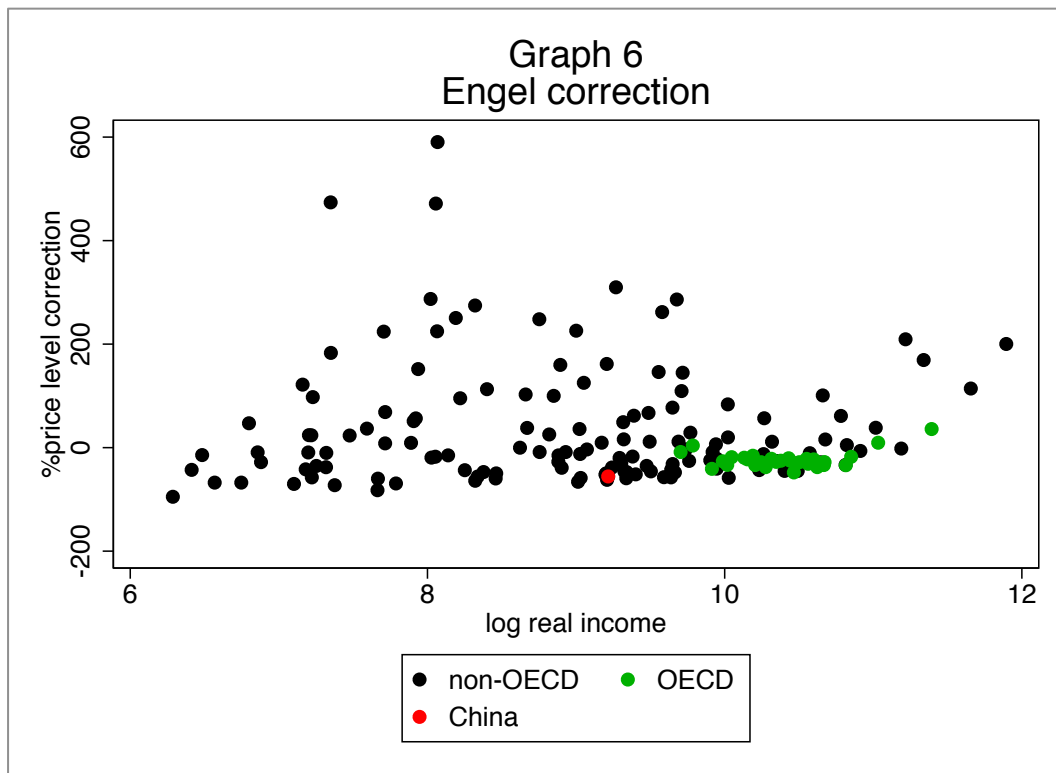
[43] In step three it is implicitly assumed that all the correction in the real income is due to biased price levels, this is however a slightly problematic assumption that will be discussed in more detail in section 5.2

As presented in graph 6, the correction for low-income countries are on average positive, as expected based on the theory discussed. *This indicates that the price levels for low-income countries are generally underestimated.* China is one of few developing countries with a negative price level adjustment. According to the Engel corrected estimates, the Chinese price level reported in the 2011 ICP is overestimated by as much as 40 percent. Accordingly, the real income is underestimated by the same amount.

The price level corrections are bigger for the low-income countries of the sample. There is, however, not a clear correlation between the magnitude of the corrections and real incomes.[44]

The Engel corrected price levels provided in this thesis is on average smaller for countries with a log real income greater than 10. Within this group, however, a clear separation between OECD and non-OECD countries is once again found. This should be expected since the Engel curve is specified over the OECD countries. The finding, does, however, hold even when the Engel curve is estimated over all countries implying that PPP bias is generally smaller for OECD countries. Furthermore, the finding may indicate that the difference in the Penn effects between OECD and non-OECD countries, as found in the analysis of this thesis, is partly driven by bigger price level bias in the non-OECD countries.

Furthermore, it should be noted that some of the revisions are of such a magnitude that they seem implausible.[45] This may be explained by the assumption of a strong relation between *real* income and the *disposable* income of the population. This link may, however, be quite week for countries with high resource rents or high-income inequality. Furthermore, there are some problems with the Engel curve that can be expected to overstate the revision of price levels for low-income countries. This will be discussed in more detail in section 5.1.8.

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[44] This is in contrast to Almaas (2012) who finds that the magnitude of the correction is negatively correlated with income (the poorer the country, the more the price level tend to be underestimated).

[45] The biggest correction is for Equatorial Guinea, with a price level correction of 1400 percent. Armenia, Mauritania, Seychelles, Tanzania and Zambia all see price level corrections higher than 700 percent.

5.1.6 Findings

Estimating the Penn effect on the Engel corrected data changes the estimated renminbi misalignment through two channels. First of all, the stark downward revision of the Chinese price level clearly has implications for the Chinese misalignment. Second, the upward revision of the price level in low-income countries changes the functional form of the Penn effect when estimated on the Engel corrected data.

The upward revision of the price level of low-income countries yields a negative slope for parts of the sample. Furthermore, the separation of the Penn effect between OECD and non-OECD countries is no longer apparent, leading to a more uniform slope for the high-income countries of the sample. In effect, the Engel corrected data is best approximated by a non-linear regression function.[46] This implies that the Chinese price level is now compared to a different Penn effect than estimated in the analysis on the ICP data.

The regression result is presented in graph 7. Both a quadratic regression and a Lowess regression is specified.[47]

Graph 7
Penn effect on corrected data

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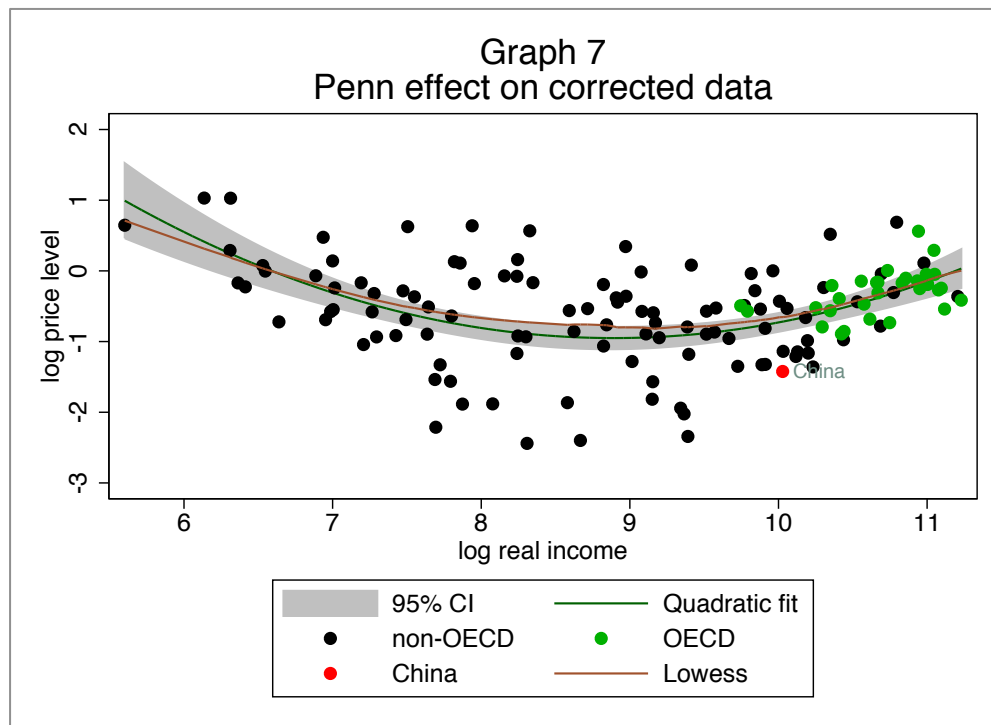
[46] A linear regression over OECD countries now provides a poorer fit for the sample (R^2 of 0.12). For a dummy regression on OECD and non-OECD countries, the interaction dummy is not statistically significantly different from zero.
[47] Liberia is excluded from the regression, as it is a clear outliner.

The real renminbi compared to the new non-linear Penn effect is *estimated to be about 50 percent undervalued*, for both regression specifications. This is a considerable revision from the result found in the analysis on the ICP data. In addition, the undervaluation is also much stronger than any of the other results presented in the literature review.

Although the estimation predicts a considerable undervaluation of the real renminbi, the average misalignment over all countries is much higher in the Engel corrected data than in the ICP data. Consequently, compared to the misalignment of other countries, the renminbi misalignment can by no means be viewed as a special case. Furthermore, it is clear that the relation between price level and real income is quite weak in the Engel corrected data. In this respect, it seems questionable to define misalignment in terms of deviation from the Penn effect regression.

Despite the fact that the Engel curve provides insightful information and corrections in this section, the method does have its problems when correcting bias in income and price levels. Nevertheless, the stark revision of the renminbi misalignment found in this section illustrates how sensitive the results of exchange rate models are to biases in the price levels.

5.1.7 Critique and problems with the Engel procedure

Although the relation between food shares and income has been widely recognized and applied in the literature on price and income inequality, some issues remains. Deaton and Dupriez (2011) and Ravallion and Bidani (1994) highlight two main drawbacks of the Engel curve for correcting real incomes and PPPs.

First of all, different compositions of households can lead to biases in the Engel corrected data. Holding income constant, food consumption may vary at different stages of life. For instance, it is often observed that children, and especially boys, eat more when they are growing up. This may result in a higher food share for household with many children. Since a higher food share yields a lower predicted real income in the Engel curve, the Engel corrected price level will be overvalued for countries with households with more young children. The households of developing countries are typically bigger and with more children, compared to developed countries. Consequently, the real income of developing

countries may be underestimated when it is predicted based on the Engel curve. Implicitly, this means that the Engel corrected price levels will be overestimated. [48]

A second concern is the effect of activity level on calorie intake on food shares. In developing countries where the population primarily performs manual labor in agriculture or manufacturing, the activity levels require a higher calorie intake than in developed countries with more capital-intensive industries. This will also inflate the food shares of developing countries and consequently deflate their Engel predicted income. However, it is well known that developed countries are struggling with problems of excessive calorie intake, and obese has become a huge problem in most modern societies. This may equalize the calorie intake across development stages, reducing the problems addressed.

The two arguments both points in the direction of underestimation of real incomes and overestimation of price levels for developing countries by the Engel procedure. This may partly explain why the price level correction of some developing countries is quite extreme. It seams reasonable to assume that the actual price level lies somewhere between the ICP reported levels, and the ones calculated with the Engel procedure.

In addition to the general critique of the Engel procedure, some of the extreme corrections between the ICP price and the Engel corrected price levels may be explained through the restricting assumption that the bias in the real incomes is only caused by biased price levels. As will be discussed in the following, part of the bias may be due to measurement errors in nominal income.

5.2 Measurement errors in nominal income

In regards to the nominal income data, the robustness of the results relies on how accurately the aggregate economic activity in a country is measured. In the ICP survey nominal incomes are based on the expenditure side of the national accounts data. All countries in the ICP survey report final expenditures according to the standardized System of National

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[48] It can be argued that this does not apply to China due to the one child policy, making the Chinese household size and demographics more similar to the developed countries societies.

Accounts (SNA).[49]

The World Bank provides a classification of countries' statistical capacity based on the availability, standard and timeliness of the components of national account data. There is a clear correlation between income levels and classifications of statistical quality, implying that the bias in GDP may be systematically screwed towards low-income countries (Chen et al. (2007)). Furthermore, by using the strong relation between satellites recorded luminosity and economic activities it is found that the national accounts data in low-income countries tend to be misreported (see amongst others Chen et al. (2011) and Henderson et al (2012)). Chen et al. (2011) find that luminosity data adds considerable information to countries with low statistical capacity; while the contribution to high-income countries with high statistical capacity is small.

It is often believed that the GDP per capita for low-income countries are undervalued. The undervaluation is caused by problems associated with informality and household production and consumption outside of the formal market structures (Gollin et al. 2014). If the nominal incomes are systematically underestimated for low-income countries, and the size of the bias is negatively correlated with income, the Penn effect coefficient may be overestimated. Holding the nominal income of China constant, this would imply that the overvaluation of the renminbi found in the analysis, is underestimated.

Furthermore, if nominal incomes are systematically undervalued for low-income countries, this yields an overestimation of the Engel corrected price levels. This follows from step three in the Engel procedure. More specifically, when the Engel corrected incomes and the nominal incomes from ICP are used to calculate new price levels, it is implicitly assumed that there is no bias in the nominal incomes.[50] Consequently, the whole difference between the nominal and real incomes is attributed to biased price levels. As mentioned above, this may explain some of the extreme corrections found for low-income countries of the sample. Moreover, the Penn effect estimated over the Engel corrected data, may be overvalued for low-income countries.

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[49] SNA is the internationally agreed standard set of recommendations on how to compile measures of economic activity (UN.org)

[50] Recall Eq. 21

5.3 Measurement errors in the exchange rates

The Penn effect regression may also be sensitive to the exchange rates. The exchange rate enters in both the explained and explanatory variables of the Penn effect regression through the price level. In the ICP data the exchange rates used to calculate the price level is average yearly exchange rates extracted from IMF. Phylaktis et al. (1994) show that the domestic price of tradable goods and hence the real exchange rate is strongly affected by large black market for foreign exchange. Consequently, if the black market exchange rates are systematically different from the official rates, this may bias the coefficient of the Penn effect. Furthermore, reducing the validity of the misalignment result found in this thesis.

Pre 1980's black market exchange rates could strongly deviate from official exchange rates in developing countries; however, Reinhart et al. (2004) find that the gap has decreased greatly over time. In recent years the Chinese government have exerted strong efforts to end the black market operations. Consequently, this has caused the deviations between the official exchange rate and the black market exchange rates to fall. Moreover, the black market operations are now relatively smaller compared to previous years (Guo, 2010). Following this line of arguments, it seems reasonable to assume that there is no considerable bias caused by the exchange rates.

6. Conclusion

In this thesis the renminbi misalignment has been investigated by applying the Penn effect model. The first finding of this thesis is that the commonly used log-linear Penn effect regression over the full sample poorly describes the relation between income and price levels. Although a difference in the Penn effect relation between high-and low-income countries has been recognized by several scholars, few attempts have been made to provide a more suitable functional form. In this thesis, it is proposed that the main difference in the Penn effect lies mainly between OECD and non-OECD countries, and not high- and low-income countries. The apparent stronger Penn effect in OECD countries is believed to be caused by a higher degree of labor mobility between tradable and non-tradable sector than in non-OECD countries. The Penn effect relation specified in this thesis yields an overvaluation of the renminbi of about 6.7 percent.

The second main finding of the thesis does, however, strongly contest this conclusion. By correcting the price levels and real incomes that are applied in the Penn effect specification, we find that the functional form of the Penn effect and the misalignment of the real renminbi is highly sensitive to well known measurement errors in PPPs. First of all, the Engel corrected price level suggests that the Chinese real renminbi is 40 percent lower than the price level suggested by the ICP data. According to the Penn effect estimated on the Engel corrected data, the real renminbi is undervalued by about 50 percent compared to the U.S. dollar. The relation between income and price levels is, however, weak for non-OECD countries, questioning the existence of a clear relation between income and price level in these countries.

The alleged manipulation of the real renminbi has been at the epicenter of the debate on the bilateral imbalances between the U.S. and China. This thesis do, however, illustrate the importance of exerting caution when drawing conclusions of currency manipulation based on real exchange rate models. Due to the definition of the real exchange rate, all models of real exchange rates must include price differences between countries. Hence, the sensitivity of the misalignment estimates to measurement errors is not only relevant for the Penn effect models, but for all models of real currency misalignment.

Appendix

A: Relative Purchasing Power Parity

Due to the shortcomings of the absolute PPP there has been developed a weaker version of the theory, known as relative PPP. The relative PPP states that the exchange rate between two countries should eventually adjust to account for differences in their inflation rates (Rogoff, 1996). To illustrate this the absolute PPP is expressed in growth rates

The absolute PPP can be expressed in growth rates as follows, where P_t and P_t^* represent the domestic and foreign price level and E_t is the exchange rate at time t.

$$(22) \qquad E_t = \frac{P_t}{P_t^*}$$

By taking the natural logarithms of both sides at two different dates, we obtain

$$(23) \qquad lnE_t = lnP_t - lnP_t^* \qquad\qquad lnE_{t+1} = lnP_{t+1} - lnP_{t+1}^*$$

$$(24) \qquad lnE_{t+1} - lnE_t = (lnP_{t+1} - lnP_t) - (lnP_{t+1}^* - lnP_t^*) = \pi_{t+1} - \pi_{t+1}^*$$

In the above equation π_{t+1} and π_{t+1}^* represent the inflation in the domestic and foreign country, respectively. If the home country is experiencing higher inflation than a country abroad, it should expect its currency to decrease in value (depreciate).

Whether relative PPP holds or not has an important implication for international trade. If PPP do not hold, this may affect a country's competitive position in the world export market. Whereas the absolute version of PPP is a theory developed for exchange rate determination, the relative version is an effective theory of determining exchange rate movements. A great advantage of the latter version is that it may hold even if absolute PPP does not hold.

B: Fundamental Equilibrium Exchange Rate approach

The approaches used for estimating the currency misalignment of renminbi can be grouped in two broad categories; the fundamental equilibrium exchange rate (FEER) approach and the extended purchasing power parity (PPP) approach (Morrison et al, 2008). Although an extended purchasing power party approached is applied in this thesis, the FEER model is here presented since problems associated with measurement errors in the PPPs is also relevant to these models.

The FEER models are complicated econometric models that require vast information to implement. In the first step of the FEER models, the fundamental equilibrium has to be defined. There are two common approaches to define the equilibrium. The first is to define it by the ratio of net foreign assets to GDP that stabilizes foreign debt, whereas the second estimates the structural domestic savings investment balance for the medium term (Dunaway and Le, 2005). The currency misalignment is then calculated as the real exchange rate correction needed to bridge the gap between the actual current account and the estimated fundamental equilibrium. The correction needed will in turn reflect the estimated or assumed price elasticity of the country´s imports and exports.

The main drawback of the FEER models is the need for a definition of equilibrium in external balances. There is no answer to what the fundamental equilibrium of a country's balance of payment is or if there even exists such a state. Most of the estimates in the literature are based on different "rule of thumb" and normative stand on what the equilibrium should be, however, there is no consensus based on theory or empirical evidence on the correct equilibrium. This makes the estimates difficult to compare across studies and, as demonstrated by Dunway et al. (2006) the result is highly sensitive to chosen equilibrium. The authors show that changing the assumed equilibrium current account balance by 2 percentage points of GDP changes the estimated undervaluation by as much as 25 percentage points.

Furthermore, it is particularly difficult to estimate the external equilibrium for China due to the capital controls of the country. The reasonable assumption of what constitutes equilibrium is highly dependent on whether China would choose to keep capital controls or not. Under a regime of capital controls, balance in the current account could be a reasonable assumption, however, if capital controls are abandoned, equilibrium could now entail

persistent lending or borrowing from private Chinese citizens to the rest of the world. This would result in equilibrium surplus or deficit on the trade balance, respectively. As China has both high national saving and investment rate it is not obvious whether the country will be a net lender or borrower if capital controls are abandoned completely. (Morrison and Labonte, 2013)

A second concern is the choice of import and export elasticity's, which will strongly influence the estimated change in the real exchange rate needed to reach balance. It is not straightforward to calculate the export and import elasticity and the elasticity will tend to change over time as a country develops. Since China is growing fast and is going through several structural changes, this problem is surely relevant for China. Furthermore, Chinese data on import and exports has been known to be systematically manipulating further aggravating the problem of biased elasticity estimates from the country.

C: List of observations and classifications

Country	Income class[51]	OECD	Oil dependent country
Albania	High-middle income	NO	NO
Algeria	High-middle income	NO	YES
Angola	High-middle income	NO	YES
Armenia	Low-middle income	NO	NO
Australia	High-income	NO	NO
Austria	High-income	YES	NO
Azerbaijan	High-middle income	NO	NO
Bahrain	High-income	NO	NO
Bangladesh	Low-income	NO	NO
Belarus	High-middle income	NO	NO
Belgium	High-income	YES	NO
Benin	Low-income	NO	NO
Bolivia	Low-middle income	NO	NO
Bosnia and Herzegovina	High-middle income	NO	NO
Botswana	High-middle income	NO	NO
Brazil	High-middle income	NO	NO
Bulgaria	High-middle income	NO	NO
Burkina Faso	Low-income	NO	NO
Burundi	Low-income	NO	NO
Cambodia	Low-income	NO	NO
Cameroon	Low-middle income	NO	NO
Canada	High-income	YES	YES
Central African Republic	Low-income	NO	NO
Chad	Low-income	NO	NO
Chile	High-income	YES	NO
China	High-middle income	NO	NO
Colombia	High-middle income	NO	NO
Congo, Dem. Rep.	Low-middle income	NO	NO
Congo, Rep.	Low-middle income	NO	NO
Costa Rica	High-middle income	NO	NO
Côte d'Ivoire	Low-middle income	NO	NO
Croatia	High-income	NO	NO
Czech Republic	High-income	YES	NO
Denmark	High-income	YES	NO
Dominican Republic	High-middle income	NO	NO
Ecuador	High-middle income	NO	YES
Egypt, Arab Rep.	Low-middle income	NO	NO
El Salvador	Low-middle income	NO	NO

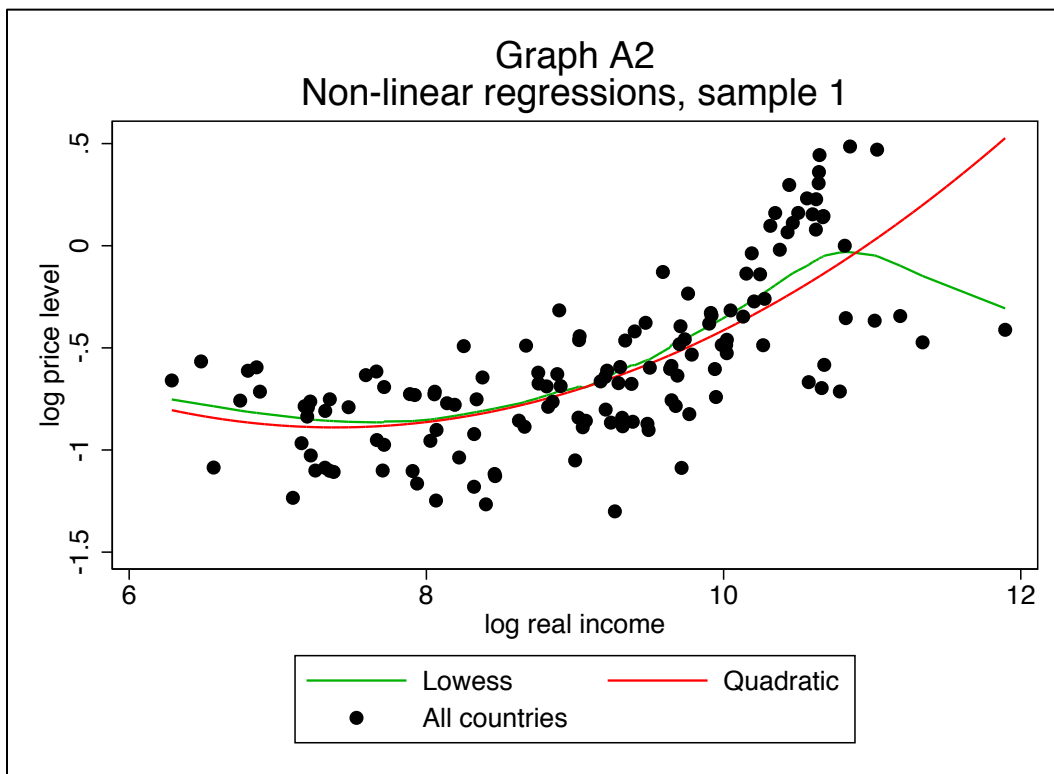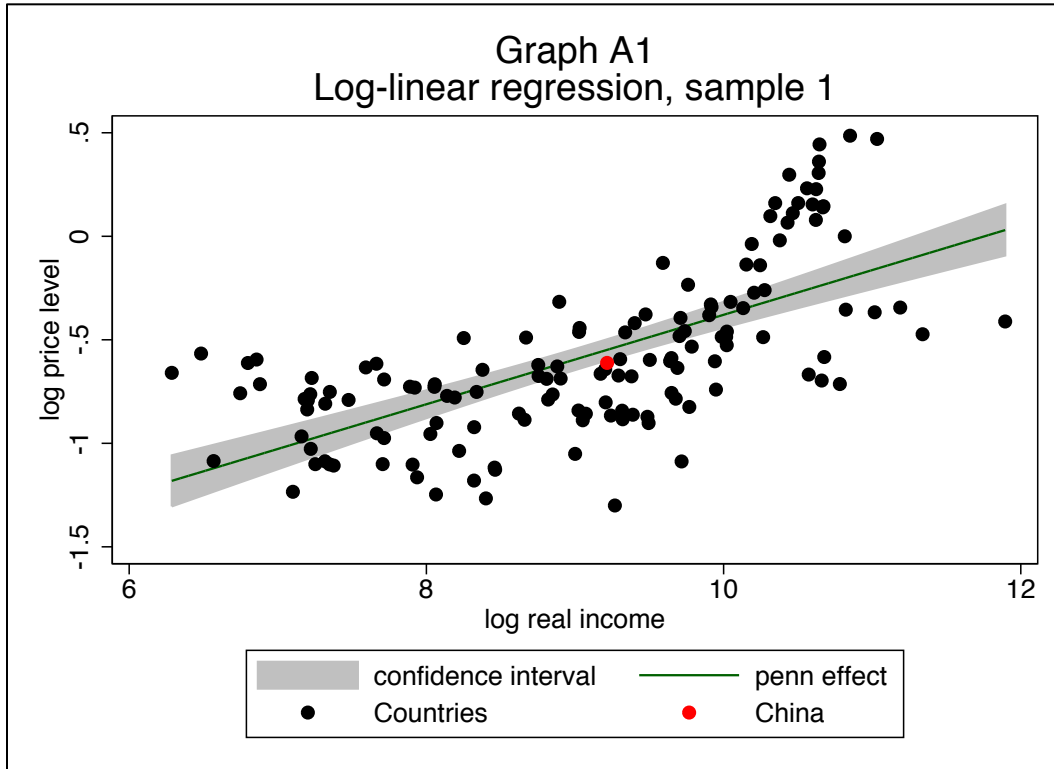[51] Income class as defined by the World Bank, 2012. The classification is based on GNI per capita.

Country	Income class[51]	OECD	Oil dependent country
Estonia	High-income	YES	NO
Ethiopia	Low-income	NO	NO
Finland	High-income	YES	NO
France	High-income	YES	NO
Gabon	High-middle income	NO	NO
Gambia, The	Low-income	NO	NO
Georgia	Low-middle income	NO	NO
Germany	High-income	YES	NO
Ghana	Low-middle income	NO	NO
Greece	High-income	YES	NO
Guatemala	Low-middle income	NO	NO
Guinea	Low-income	NO	NO
Guinea-Bissau	Low-income	NO	NO
Haiti	Low-income	NO	NO
Honduras	Low-middle income	NO	NO
Hong Kong SAR, China	High-income	NO	NO
Hungary	High-middle income	YES	NO
India	Low-middle income	NO	NO
Indonesia	Low-middle income	NO	NO
Iran, Islamic Rep.	High-middle income	NO	YES
Iraq	High-middle income	NO	YES
Ireland	High-income	YES	NO
Israel	High-income	YES	NO
Italy	High-income	YES	NO
Jamaica	High-middle income	NO	NO
Japan	High-income	YES	NO
Jordan	High-middle income	NO	NO
Kazakhstan	High-middle income	NO	YES
Kenya	Low-income	NO	NO
Korea, Rep.	High-income	YES	NO
Kuwait	High-income	NO	YES
Kyrgyzstan	Low-middle income	NO	NO
Lao PDR	Low-middle income	NO	NO
Latvia	High-income	NO	NO
Lesotho	Low-middle income	NO	NO
Liberia	Low-income	NO	NO
Lithuania	High-income	NO	NO
Macedonia, FYR	High-middle income	NO	NO
Madagascar	Low-income	NO	NO
Malawi	Low-income	NO	NO
Malaysia	High-middle income	NO	NO
Mali	Low-income	NO	NO
Mauritania	Low-middle income	NO	NO

Country	Income class[51]	OECD	Oil dependent country
Mauritius	High-middle income	NO	NO
Mexico	High-middle income	YES	NO
Moldova	Low-middle income	NO	NO
Mongolia	Low-middle income	NO	NO
Morocco	Low-middle income	NO	NO
Mozambique	Low-income	NO	NO
Myanmar	Low-income	NO	NO
Namibia	High-middle income	NO	NO
Nepal	Low-income	NO	NO
Netherlands	High-income	YES	NO
New Zealand	High-income	YES	NO
Nicaragua	Low-middle income	NO	NO
Niger	Low-middle income	NO	NO
Nigeria	Low-middle income	NO	YES
Norway	High-income	YES	YES
Oman	High-income	NO	NO
Pakistan	Low-middle income	NO	NO
Palestinian Territory	#N/A	NO	NO
Panama	High-middle income	NO	NO
Paraguay	Low-middle income	NO	NO
Peru	High-middle income	NO	NO
Philippines	Low-middle income	NO	NO
Poland	High-income	YES	NO
Portugal	High-income	YES	NO
Qatar	High-income	NO	YES
Romania	High-middle income	NO	NO
Russian Federation	High-income	NO	YES
Rwanda	Low-income	NO	NO
Saudi Arabia	High-income	NO	YES
Senegal	Low-middle income	NO	NO
Serbia	High-middle income	NO	NO
Sierra Leone	Low-income	NO	NO
Singapore	High-income	NO	NO
Slovakia	High-income	YES	NO
Slovenia	High-income	YES	NO
South Africa	High-middle income	NO	NO
Spain	High-income	YES	NO
Sri Lanka	Low-middle income	NO	NO
Sudan	Low-middle income	NO	NO
Swaziland	Low-middle income	NO	NO
Sweden	High-income	YES	NO
Switzerland	High-income	YES	NO
Taiwan, China	#N/A	NO	NO

Country	Income class[51]	OECD	Oil dependent country
Tajikistan	Low-income	NO	NO
Tanzania	Low-income	NO	NO
Thailand	High-middle income	NO	NO
Togo	Low-income	NO	NO
Trinidad and Tobago	High-income	NO	NO
Tunisia	High-middle income	NO	NO
Turkey	High-middle income	YES	NO
Uganda	Low-income	NO	NO
Ukraine	Low-middle income	NO	NO
United Arab Emirates	High-income	NO	YES
United Kingdom	High-income	YES	NO
United States	High-income	YES	NO
Uruguay	High-income	NO	NO
Venezuela, RB	High-middle income	NO	YES
Vietnam	Low-middle income	NO	NO
Yemen	Low-middle income	NO	NO
Zambia	Low-middle income	NO	NO

D: Graphical presentation of the Penn effect regressions

All the regressions presented in this section are based on the 2011 ICP data.

Graph A1
Log-linear regression, sample 1

Graph A2
Non-linear regressions, sample 1

Graph A3
Non-linear regressions, sample 2
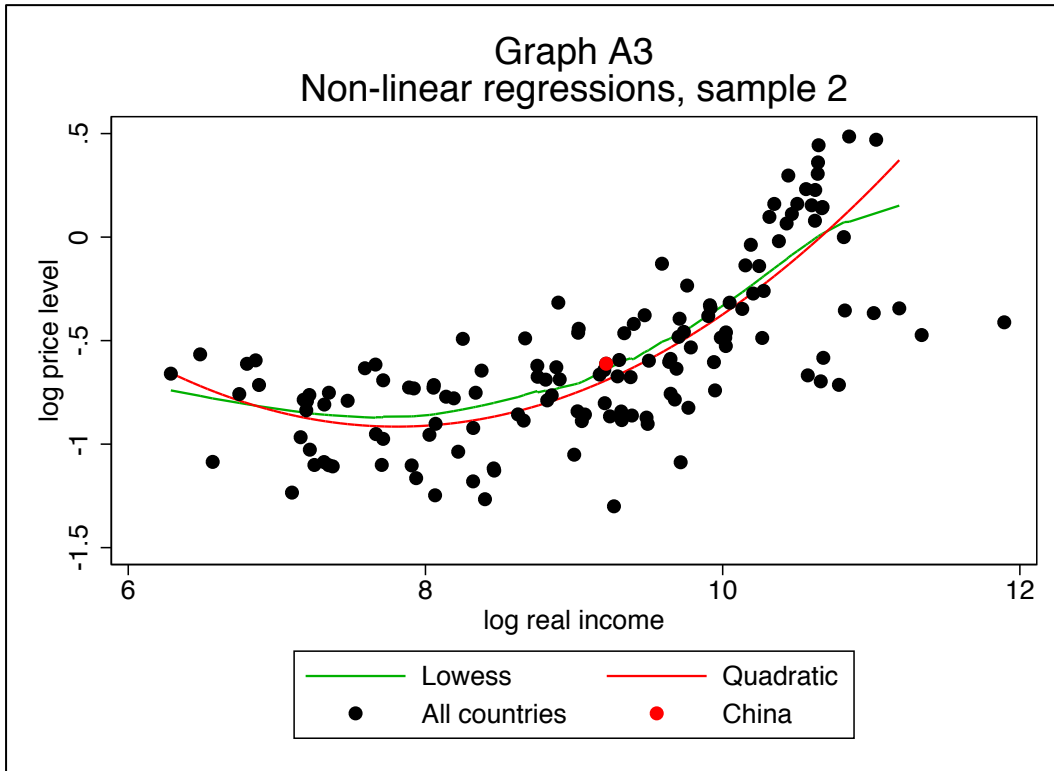
E: Are oil exporters following a different Penn effect?

In the literature, Oil dependent countries have been shown to follow different real exchange rate adjustments than predicted by the Penn effect. Chen and Choi (2007) investigates the long run relationship between oil prices and real exchange rate in G7 countries and fin that the real oil prices may be the dominant source of movement in the real exchange rate. Korhonen and Juurikkala (2007) investigate the real equilibrium exchange rate of oil dependent nations through a BEER model and find that oil price is the only variable with consistent and statistically significant effect on the real exchange rate of these countries. Comparative Price levels in oil dependent countries are generally believed to be higher due to Dutch disease phenomenon and the higher price level is supported theoretically by Clauge (1985), who find that factor endowment of natural resources increases relative price levels.

An interesting observation made when examining the functional form of the Penn effect, was the stark improvement in the fit of the non-linear regression from sample one to sample two. Oil exporting countries have commonly been excluded from Penn effect regression and Kessler and Subramanian (2014) find that the Penn effect is best approximated by a quadratic function when excluding these countries.

As is apparent from graph A4, this improvement in regression fit is driven by the reduction of countries with high-income and low price levels in the sample.

Graph A4
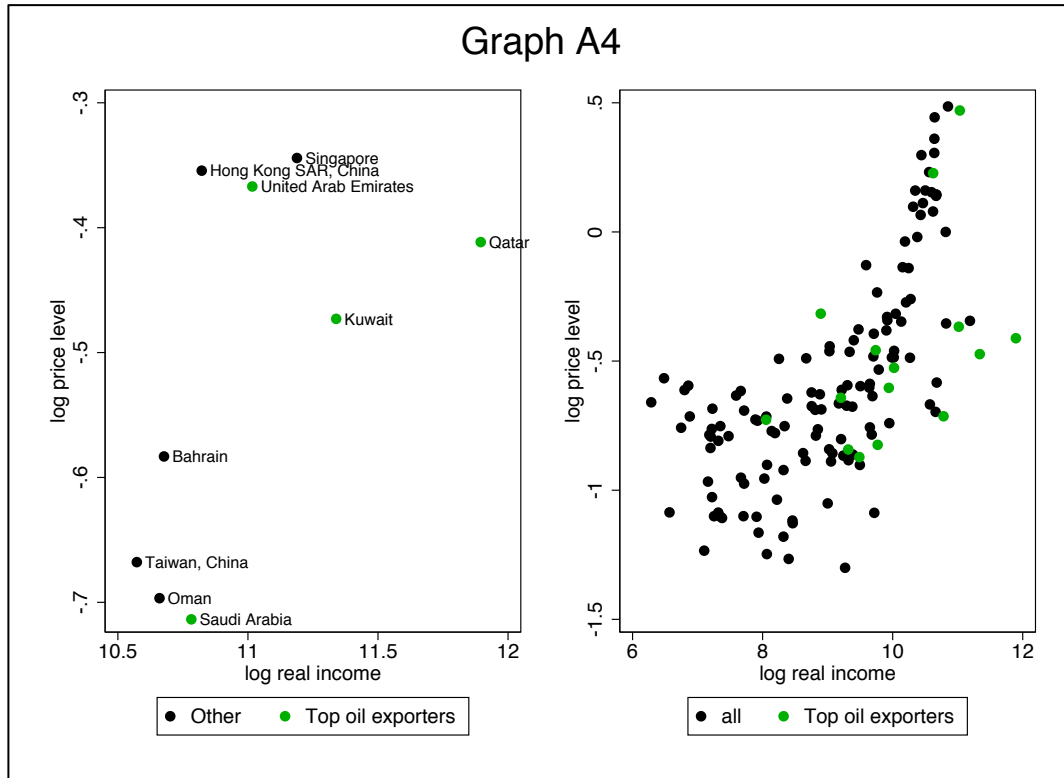
The left part of the graph shows names and categorization for the high-income countries with low price levels. Many of these countries are top oil exporters.[52] This finding is quite puzzling; the theory presented suggests that oil dependent countries should experience high, not low price levels. Furthermore, a closer look at the right part of graph A4 reveals that these groups do not necessarily follow a different pattern than the rest of the countries in the sample. Both factors question the rationale behind excluding these countries in the Penn effect regression.

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[52] Noticeable exceptions are Bahrain and Oman, which also have a high share of oil production in GDP.

F: The Measurement error bias in the Penn effect regression

One of the basic assumptions to get unbiased and consistent estimates in an OLS regression is that the explanatory variable (in the Penn effect regression, real income) is uncorrelated with the error term. In the Penn effect regression this is, however, not the case hence the Penn effect coefficient β will be biased downwards. In the following section the calculations behind this result is presented. The calculations are based on the presentation of Chen and Choi (2007).

Lets assume that the following relation holds for the true value of the price level, p_i^* and the real GDP per capita $y_i^* = Y_i - p_i^*$ both in logarithms (Y is nominal income).

(25) $p_i^* = \alpha + \beta y_i^* + \varepsilon_i$

Suppose the measured price level, p_i, contains a measurement error, v_i, which has a mean of zero and is normally distributed. Then p_i can be expressed as follows:

(26) $p_i = p_i^* + v_i$

Using this and the definition of y_i it is found that

(27) $y_i = Y_i - p_i = Y_i - (p_i^* + v_i) = y_i^* - v_i$

Hence both the estimated price level and real income can be expressed in terms of the error term and any error in the price level will produce an equal and offsetting error in the estimated real GDP per capita.

(28) $p_i - v_i = \alpha + \beta(y_i + v_i) + \varepsilon_i$

Rearranging the above equation, it becomes evident that the independent variable is correlated with the error term, redefined as w_i, leading to the biased and inconsistent estimates of the B coefficient.

(29) $p_i = \alpha + \beta y_i + w_i, \qquad w_i = v_i(\beta + 1) + \varepsilon_i$

Further more, it can be shown that the measurement error will bias the OLS estimate $\hat{\beta}$ downwards. In an OLS regression the $\hat{\beta}$ is defined as follows:

$$(30) \quad \hat{\beta} = \frac{\left(\frac{1}{n}\right)\Sigma_i(y_i - \bar{y})(p_i - \bar{p_i})}{\left(\frac{1}{n}\right)\Sigma_i(y_i - \bar{y})^2} = \frac{\left(\frac{1}{n}\right)\Sigma_i((y_i^* - \bar{y}^*) - v)(\beta(y_i^* - \bar{y}^*) + \varepsilon_i + v_i}{\left(\frac{1}{n}\right)\Sigma_i((y_i^* - \bar{y}^*) - v)^2}$$

$$(31) \quad \hat{\beta} = \frac{\left(\frac{1}{n}\right)(\beta\,\Sigma_i(y_i^* - \bar{y}^*)^2 - \beta\,\Sigma_i(y_i^* - \bar{y}^*)\;\; v_i - \Sigma_i v_i{}^2 - \Sigma_i v_i\varepsilon_i)}{\left(\frac{1}{n}\right)(\Sigma_i(y_i^* - \bar{y}^*)^2 - 2\,\Sigma_i(y_i^* - \bar{y}^*)v_i + \Sigma_i v_i{}^2)}$$

Since $\varepsilon_i, v_i \; and \; y_i^*$ are independent the following must hold

$$(32) \quad plim\frac{1}{n}\sum_i(y_i^* - \bar{y}^*)v_i = plim\frac{1}{n}\sum_i(\varepsilon_i v_i) = 0$$

By defining $\sigma_{y*}^2 = plim\left(\frac{1}{n}\right)(\beta\,\Sigma_i(y_i^* - \bar{y}^*)^2$ and using the Slutsky theorem, the probability limits of $\hat{\beta}$ can be obtained:

$$(33) \quad plim\hat{\beta} = \frac{plim\left(\frac{1}{n}\right)(\beta\,\Sigma_i(y_i^* - \bar{y}^*)^2 - \beta\,\Sigma_i(y_i^* - \bar{y}^*)\;\; v_i - \Sigma_i v_i{}^2 - \Sigma_i v_i\varepsilon_i)}{plim\left(\frac{1}{n}\right)(\Sigma_i(y_i^* - \bar{y}^*)^2 - 2\,\Sigma_i(y_i^* - \bar{y}^*)v_i + \Sigma_i v_i{}^2)} =$$

$$= \frac{\beta\sigma_{y*}^2 - \sigma_v^2}{\sigma_{y*}^2 + \sigma_v^2}$$

Further more we divide the expression by σ_{y*}^2 to isolate β:

$$(34) \quad plim\hat{\beta} = \frac{\beta\sigma_{y*}^2 - \sigma_v^2}{\sigma_{y*}^2 + \sigma_v^2} = \frac{\beta - \frac{\sigma_v^2}{\sigma_{y*}^2}}{1 + \frac{\sigma_v^2}{\sigma_{y*}^2}}$$

The calculations illustrates that if β is positive the OLS estimated $\hat{\beta}$ will be biased downwards and can even become negative for sufficiently high variances of the measurement errors.

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