RMB Undervaluation and Appreciation

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Abstract

The bilateral real exchange rate between Chinese renminbi (RMB) and the US dollar is studied. The panel data Penn effect model shows that the RMB was overvalued in 1980–1991 but later undervalued in 1992–2010. In 2010, it was undervalued by 36.7%. Econometric analysis and an examination of the appreciation of seventeen currencies belonging to countries and areas under the same economic development stage show that the RMB should appreciate at an annual speed of 3.2%. At this rate, the RMB misalignment in 2010 will be corrected by 2020. In the future, RMB appreciation should be realized totally from the nominal exchange rate, not partly from the nominal exchange rate and partly from the relative price level. This appreciation path satisfies the interests of both China and the US.

JEL classification: F31; F41

Keywords: Chinese renminbi; Real exchange rate; Penn effect; Undervaluation; Appreciation

1. Introduction

After more than 30 years of robust economic growth at an annual GDP growth rate of 9.9% from 1978 to 2010, China has finally surpassed Japan in terms of GDP and Germany in terms of both exports and imports. China is now the second largest country both in economy and external trade volume. In 2010, China accounted for 9.4% of the world's GDP, 9.3% of the world's exports of goods and services, and 8.2% of the world imports of goods and services, next only to the US. With its rising global economic presence, China has accumulated a huge trade surplus, especially in its bilateral trade with the US. Meanwhile, the US has accumulated a huge trade deficit. From 1983 to 2010, China maintained an annual (goods) trade surplus with the US. The annual bilateral trade surplus increased from US$0.3 billion in 1983 to US$291.1 billion in 2010. In 2010, the US trade deficit with China amounted to 2% of its GDP (US$14586.7 billion). [1] Many experts, including Bergsten (2010), blame the undervalued renminbi (RMB) for the huge US trade deficit with China.

Given the foregoing background, the RMB exchange rate, particularly its undervaluation and appreciation, has become controversial in recent years. Frankel (2005), using the Penn effect model and cross-section data, concluded that the RMB was undervalued by 36.1% in 2010 and proposed an annual real exchange rate appreciation of 4% for ten years or more toward an equilibrium value. Wang et al. (2007), using the behavioral equilibrium exchange rate (BEER) model and the Johansen cointegration technique, concluded that RMB fluctuates around its long-run equilibrium rate within a narrow band, suggesting that it has not been consistently undervalued. Zhang and Wan (2008), using the structural VAR model to analyze sources of China's trade balance fluctuations, concluded that although the RMB is undervalued, changes in the exchange rate has little effect on trade balance. By examining some economies that have experienced real currency appreciation against the US dollar in 1985–2005, Xu (2009) found that the mode of faster wage growth and inflation is as common as nominal appreciation, and asserted that the real appreciation of RMB will contribute to restructuring China's economy toward a domestic demand-based growth track. Cheung et al. (2010) highlighted challenges in properly assessing the nature and degree of currency misalignment, and discussed the implications of sampling uncertainty on determining the extent of RMB misalignment. Cline and Williamson (2011), using the fundamental equilibrium exchange rate (FEER) model, concluded that the RMB was undervalued by 10.6% in late October in 2011. Eichengreen (2011, p. 728) stressed that, in the process of RMB internationalization, exchange rate flexibility must be enhanced, and this entails China abandoning the strategy of maintaining an undervalued exchange rate to stimulate the export of manufactures.

In reality, responding to US pressure, China has been adjusting its exchange rate regime and appreciating the RMB since July 2005. Before the reform in July 2005, the nominal exchange rate was 8.3 yuan per US dollar. Until February 2012, the rate had appreciated by 24.1% [(8.3-6.3)/8.3] or 31.7% [(8.3-6.3)/6.3], resulting in an exchange rate of less than 6.3 yuan per US dollar. However, the call for greater RMB appreciation has not been abated. For example, during his recent visit to China in January 2012, US Treasury Secretary Geithner again stressed that China should continue to let its currency appreciate.[2] The US expects RMB appreciation, which is too slow, to increase US exports and reduce the US trade deficit (Bergsten, 2010). Meanwhile, China seeks to continue promoting the RMB exchange rate mechanism's reform at a gradualist approach; China maintains that the RMB exchange rate is not the basic reason behind the US trade deficit.[3] As long as China is running a trade surplus with the US, the RMB will always be pressured to appreciate, and the dispute between the two biggest economies will not end. In China,

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This paper was finished in May 2012. A main hypothesis about the discussion of RMB appreciation is that China's economy can continue to grow in the future as in its past thirty years.

[1] GDP growth rate is measured at constant prices. GDP, exports, and imports are measured in current US dollar. All relevant data are from the World Bank's World Development Indicators (WDI) online database, IMF's Direction of Trade Statistics (DOTS) online database, and the author's calculation. Note that the bilateral goods trade reported by the US is different from that reported by China. In the text, the former is used.

[2] *Renminbi not the problem*, available at http://usa.chinadaily.com.cn/epaper/2012-01/16/content_14453594.htm.

[3] *China says yuan rise can't solve trade imbalance with US*, available at http://www.reuters.com/article/2011/09/23/us-china-usa-yuan-idUSTRE78M1P020110923.

policymakers worry about the negative effects of RMB appreciation on export and employment, as simulated and proven by Frenkel and Ros (2006), Zhang and Fung (2006), and Thorbecke and Zhang (2009). In addition, policymakers do not have enough knowledge on how to appreciate RMB in the long run.

This paper discusses the RMB real exchange rate's undervaluation and appreciation to add new understanding to the field. We follow the ideas of Frankel (2005) and Xu (2009), who both discussed RMB undervaluation and appreciation, but we use a different empirical method. This paper is organized as follows. Section 2 calculates how the RMB was undervalued in 1980–2010 using the panel data Penn effect model. Section 3 discusses which speed of RMB appreciation is feasible in the context of international comparison and scenario forecasting. Section 4 discusses which path of RMB appreciation is desirable, through nominal exchange rate or through relative price level, from an international comparison and empirical analysis. The conclusion is given in Section 5.

2. How is RMB undervalued?

Among many models used in calculating RMB misalignment, the most appropriate one for the purposes of this study is the Penn effect model because this model can be used not only to assess how RMB is undervalued (in this section) but also to analyze the speed and path of RMB appreciation (Sections 3 and 4). The Penn effect model has been used broadly in RMB valuation studies (e.g., Takeuchi, 2003; Chang and Shao, 2004; Frankel, 2005; Xu, 2009; Cheung et al. 2007, 2010). In this study, we follow Cheung et al. (2010, p. 274–275) and use the term "Penn effect model."

2.1. Model and data

The Penn effect model is based on absolute purchasing power parity (PPP), the most basic and influential model for assessing bilateral nominal exchange rates (NER). The PPP model uses Eq. (1), where RER is real exchange rate, P is a country's domestic price level, P^* is the specified foreign country's price level (in this paper, US price level), and NER is the bilateral nominal exchange rate expressed as the national currency unit per US dollar. Given this definition, a greater RER value implies its appreciation, whereas a smaller NER value implies its appreciation. In the PPP model, whether NER equals its PPP rate is decided by the value of RER. If RER is equal to 1, NER is equal to its PPP rate and is at equilibrium; otherwise, it is over- or undervalued. Given this definition, RER also refers to a country's price level (relative to the US), as used in the Penn World Table (PWT) database.

$$RER = \frac{PPP}{NER} = \frac{P/P^*}{NER} = \frac{P}{NER \cdot P^*} \tag{1}$$

The RERs (in this definition) in rich countries are higher and those in poor countries are smaller, making deviation from the PPP common. This empirical regularity was documented in a series of studies by economists in the University of Pennsylvania, hence the term "Penn effect" (Isard, 2007, p. 10; Cheung et al., 2010, p. 274–275). Based on the Penn effect, the Penn effect model uses Eq. (2) or its linear form to value a currency's RER. In Eq. (2), RER is defined by Eq. (1), $GDPP$ is GDP per capita representing income level or economic development stage, and subscripts i and t denote panel data dimensions. Eq. (2) regresses the RERs of countries on their income levels, so deviations from the regression line represent the over- or undervaluation of RERs when the Penn effect is taken into account.

$$\log(RER_{i,t}) = b_0 + b_1 \log(GDPP_{i,t}) + u_{i,t} \tag{2}$$

In this section, all data are from the World Bank's World Development Indicators (WDI) online database. The RER labeled "PPP conversion factor to official exchange rate ratio" in the database and $GDPP$ (in current US dollar, relative to the US) can be directly obtained. We first sequence all the available countries and areas by their GDP (in current US dollar) and choose the biggest 20 countries and areas. Euro countries adopted inconsistent currencies before and after 1999, so we delete Germany, France, Italy, Spain, Netherlands, and Belgium. In the end, the other 14 biggest countries are used: United States, China, Japan, United Kingdom, Brazil, India, Canada, Russia, Mexico, Korea, Turkey, Indonesia, Switzerland, and Poland. The sample period is 1980–2010 because RER data before 1980 cannot be obtained.

2.2. Panel estimation and RMB misalignment

Table 1 gives results of the redundant fixed effect test. The associated p-values of the statistics strongly reject the null hypothesis that the cross-section effects, period effects, or both of the effects are redundant. The two-way fixed effects estimation is appropriate and is then used.

Table 1
Redundant fixed effects tests

Effects test	Statistic	Degree of freedom	P-value
Cross-section F	33.175	(13,370)	0.000
Cross-section Chi-square	320.674	13	0.000
Period F	1.994	(30,370)	0.002
Period Chi-square	62.189	30	0.001
Cross-section/Period F	12.326	(43,370)	0.000
Cross-section/Period Chi-square	368.892	43	0.000

Note: The panel is unbalanced because data for Poland before 1990 and that for Russia before 1989 are lacking.

The main estimation result is given in Eq. (3). Values in parentheses below the coefficients are their t-statistics (second line) and associated p-values (third line). The slope coefficient is highly significant, confirming the existence of the Penn effect. The slope value (0.418) is close to those in similar regressions by Frankel (0.382; 2005, p.22) and Cheung et al. (0.391; 2007, p.769). In addition, when White cross-section or period robust standard errors are used, the slope is still significant; R^2=0.916, which means the regression is a good fit.

$$\log(RER_{i,t}) = \underset{\substack{(6.075)\\(0.000)}}{0.278} + \underset{\substack{(15.178)\\(0.000)}}{0.418} \log(GDPP_{i,t}) + u_{i,t} \quad (3)$$

R^2=0.916, observations=415

The equilibrium *RER*, the fitted value of *RER*, can be solved from Eq. (3). Subsequently, the needed appreciation or depreciation, which is interpreted as misalignment in this paper, can be calculated using (*RER*-equilibrium *RER*)/*RER*. For example, in 2010, the RMB RER was 58.3 (US=100) and the equilibrium RMB RER was 79.7, so the RMB RER should appreciate by 36.7% [the absolute value of (58.3-79.7)/58.3] to its equilibrium value. In this case, RMB RER was undervalued by 36.7%.[4] The misalignment of RMB RER in the whole period is depicted in Fig. 1.

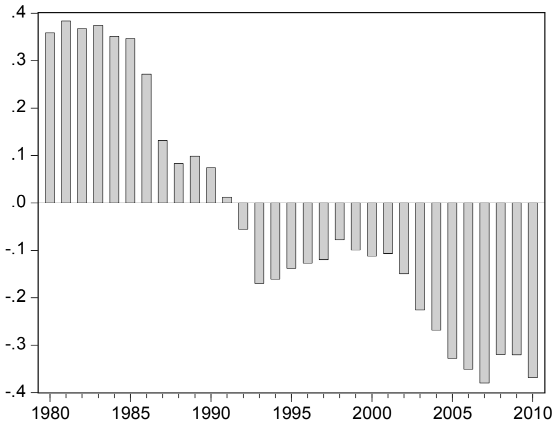

Fig. 1. Misalignment of RMB RER in 1980–2010.
Note: Negative (positive) values represent undervaluation (overvaluation).

Figure 1 shows that RMB RER misalignment evolved radically from 1980 to 2010. In 1980–1991, RMB was overvalued, and overvaluation declined from about 35% in the early 1980s to 1% in 1991. RMB became undervalued afterwards in 1992–2010. From 1992 to 2001, the RMB was undervalued by around 10%, with the smallest undervaluation (6%) in 1992 and the biggest undervaluation (about 16%) in 1993–1994. However, after 2002, the degree of undervaluation increased from 15% in 2002 to more than 30% in 2005–2010. In 2010, the RMB was already undervalued by 36.7%.

The evolution of RMB misalignment can be explained mostly by changes in RMB RER and China's economic growth. Equation (3) suggests that equilibrium RER will increase as the GDP per capita (GDPP) increases and that a RER higher (lower) than its fitted value will be overvalued (undervalued). In 1980–1991, RMB RER was priced higher, and it decreased from about 70 (US=100) in the early 1980s to less than 40 in 1991. Meanwhile, China's GDPP, measured by current US dollar and relative to the US, remained small with slight changes; it was around 1.5 (US=100) in the same period. These two factors led to a RMB RER that was higher than its fitted value (overvalued), but the degree of undervaluation decreased. In 1992–2001, RMB RER mostly fluctuated at around 40, but China's GDPP doubled (from 1.5 to 2.9), leading to a RMB RER that was lower than its fitted value (undervalued). In 2002–2010, RMB RER increased slightly, from 40 in 2002 to 58 in 2010. However, China's GDPP tripled, from 3 in 2002 to 9 in 2010, resulting in an increasing and high degree of RMB RER undervaluation.

3. Speed of RMB appreciation

Given that RMB RER was undervalued by 36.7% in 2010, we now focus on how it should appreciate to its equilibrium value. We analyze this issue from two views: speed of appreciation (discussed in this section) and path of appreciation (Section 4).

3.1. Speed of RMB appreciation in the past and an international comparison

To understand the speed of RMB RER appreciation in a comprehensive and objective manner, we follow Xu (2009) and analyze RMB appreciation in a comparative manner. We calculate and compare the annual appreciation speed of RMB and other similar currencies to determine if the speed of RMB appreciation is slower.

China's economy has been rapidly growing since its reform and opening up, so 17 countries and areas in their fast economic growth stages, such as Japan in 1950–1991 and Korea in 1965–1996, are chosen and listed in Table 2. Fast growth is measured by the (compound) annual growth rate of the country's GDPP relative to the US (US=100 in each year), where an annual

[4] The other misalignment is measured by (RER-equilibrium RER)/equilibrium RER, as in Frankel (2005).

growth rate greater than zero means that the country's GDPP grows faster than that of the US. The 17 chosen countries and areas in their respective periods all showed faster GDPP growth compared with the US, with most having GDPP growth rates greater than that of the US by more than 1.5%. China's exchange rate was reformed greatly in 1994 and 2005, so two periods for RMB were chosen, one beginning in 1994 and the other beginning in 2005.

The annual RER growth rates (RER annual appreciation speed) and GDPPs of relevant countries and areas in their fast economic growth stages are calculated and listed in Table 2. The countries and areas are sequenced in descending order by the annual RER growth rates of their currencies. The annual RER growth rate does not consider economic growth status, which differs across countries, so we also examine RER appreciation speed in the background of economic growth status. This can be done by calculating and comparing the slopes in Eq. (4), which is the reduced form of the panel data regression in Eq. (2) in its time-series data situation.

$$\log(RER_t)=b_0+b_1\log(GDPP_t)+u_t \tag{4}$$

Most of the chosen countries and areas began their fast economic growth before 1980, but the WDI includes only RERs after 1980. Thus, we use another database, the Penn World Table (PWT) 7.0, which provides RERs [defined by Eq. (1)] and GDPPs (PPP converted, US=100 in each year) for 189 countries and areas for some or all of the years in 1950–2009. For China, the RERs and GDPPs in their same definitions in the PWT are different from those in the WDI, so both databases are used, with data from the PWT and WDI denoted by the subscripts PWT and WDI, respectively.[5]

Before estimating Eq. (4), we first consider unit root and cointegration tests for the variables. Observations for China in 2005–2009 and 2005–2010 are too few, so we do not perform unit root and cointegration tests for them. The ADF unit root test reveals that all the other variables, except those for Romania, Finland, Taiwan, and Thailand, depict I(1) behavior. Meanwhile, the cointegration test (Engle–Granger test for Norway and Johansen test for the others) reveals that there is at least a cointegration relationship in each group. For Romania, the ADF unit root test reveals that the two variables depict I(2) behavior, and Johansen test reveals that there exists cointegration relationship between them. For Finland, Taiwan, and Thailand, all the variables are stationary. Hence, for each group, Eq. (4) can be estimated. The b_1 coefficients and their p-values are listed in the last column of Table 2.

[5] The GDPP used in this section (Section 3) and in Section 4 is PPP converted, but that used in Section 2 is current US dollar converted. For China, the PPP converted GDPP is significantly greater than the current US dollar converted one.

Table 2
Changes in RERs and GDPPs of relevant countries and areas in their fast economic growth stages

Country and area	Period: first year last year	RER (US=100 in each year)		GDPP (US=100 in each year)		b_1 for log(*RER*) in Eq. 4: coefficient (p-values)
		Value in first year Value in last year	Annual growth rate	Value in first year Value in last year	Annual growth rate	
Russia	1999	20.7	11.7%	19.5	5.9%	1.83
	2009	62.2		34.4		(0.00)
Romania	1999	32.7	7.1%	14.6	5.8%	1.43
	2009	64.9		25.7		(0.00)
$China_{WDI}$	2005	42.1	6.7%	9.7	10.7%	0.67
	2010	58.3		16.1		(0.00)
$China_{PWT}$	2005	37.2	7.1%	11.1	12.5%	0.65
	2009	48.9		17.8		(0.00)
Korea	1965	26.8	3.6%	10.6	5.3%	0.55
	1996	81.2		52.3		(0.00)
Japan	1950	30.8	3.5%	23.7	3.5%	0.86
	1991	128.5		96.4		(0.00)
Nether-land	1951	42.3	3.5%	66.7	1.6%	2.18
	1975	96.8		98.0		(0.00)
$China_{PWT}$	1994	29.8	3.4%	6.1	7.4%	0.32
	2009	48.9		17.8		(0.00)
$China_{WDI}$	1994	35.0	3.2%	5.0	7.6%	0.33
	2010	58.3		16.1		(0.00)
Poland	1991	39.8	2.9%	23.5	3.0%	1.07
	2009	66.8		40.3		(0.00)
Germany	1970	71.1	2.4%	77.4	0.5%	3.60
	1992	120.2		87.0		(0.00)
Thailand	1985	39.4	2.4%	11.1	5.8%	0.34
	1996	51.0		20.7		(0.00)
Finland	1959	67.5	2.3%	55.3	1.3%	1.40
	1989	131.9		81.4		(0.00)
Taiwan	1965	43.8	1.9%	13.7	4.9%	0.45
	1996	78.4		60.0		(0.00)
Spain	1953	43.2	1.9%	29.0	3.7%	0.23
	1975	65.2		63.9		(0.30)
Norway	1953	62.9	1.8%	67.9	1.5%	1.99
	1982	104.1		103.8		(0.00)
Singapore	1965	55.1	1.6%	25.2	4.5%	0.29
	1996	91.3		97.2		(0.00)
Sweden	1952	74.9	1.2%	75.8	1.8%	0.56
	1964	86.0		94.0		(0.00)
Italy	1952	47.6	1.1%	41.0	2.2%	0.81
	1982	67.1		78.1		(0.00)
Hong Kong	1960	68.1	0.9%	19.8	4.6%	0.15
	1993	91.8		86.8		(0.04)
France	1951	74.5	0.5%	52.2	1.6%	0.59
	1982	87.3		84.8		(0.02)

Notes: The (compound) annual growth rate x is obtained from $a\cdot(1+x)^n=b$, where a and b are values in the first and last year, respectively, and n is the number of years examined. The associated p-values for the coefficients in Eq. (4) are calculated using Newey–West HAC standard errors. China refers only to mainland China.
Source: WDI (only for data on RER and GDPP in $China_{WDI}$), PWT 7.0, and author's calculation.

First, we examine the annual growth rates (annual appreciation speed) of the listed RERs, which vary greatly from 0.5% (France) to 11.7% (Russia). In 2005–2010, the annual RER appreciation speed of RMB (6.7%) ranks only below that of the Russian ruble and Romanian new leu. Meanwhile, in 1994–2010, the annual RER appreciation speed (3.2%) of RMB ranks below that of five other currencies. The foregoing values, calculated using the WDI database, are roughly similar to those calculated for 2005–2009 and 1994–2009 using the PWT database. In addition, seen from the values, the annual RER appreciation speed of RMB (3.2–3.4% in 1994–2010 or 1994–2009) is very near that of the Korean won, Japanese yen, and Netherlands Antillian guilder (3.5–3.6%). The annual RER appreciation speed of RMB in 2005–2010 or 2005–2009 (6.7–7.1%) is even about twice that of the Korean won, Japanese yen, and Netherlands Antillian guilder. Therefore, in the list of comparable eighteen currencies, the annual appreciation speed of RMB RER is in the front row.

Second, we examine coefficient b_1 from Eq. (4), which measures RER appreciation speed when economic growth status is considered. The coefficients also vary greatly as in the case of annual RER growth rates, from the highest value of 3.6 (Germany) to the lowest value of 0.15 (Hong Kong), but gives different information. Only seventeen coefficients are considered because b_1 for Spain is not significant. In terms of RMB RER in 2005–2010 (or 2005–2009), the coefficient is 0.67 (or 0.65), ranking tenth, above that of the Italian lira and below that of the French franc. In addition, although RMB ranks at the middle, the coefficient is relatively small, only about one sixth that of D-mark (the greatest), 0.67 vs. 3.6. In terms of RMB RER in 1994–2010 (or 1994–2009), the coefficient is 0.33 (or 0.32), ranking fifteenth, above only that of Singapore dollar and Hong Kong dollar. Therefore, in the list of comparable seventeen currencies with significant coefficients, the RMB ranks at the middle but with a relatively small value in 2005–2010. However, in 1994–2010, RMB ranks near the bottom. Under the background of economic growth, the speed of RMB RER appreciation indeed seems a bit slow.

Compared with other similar seventeen currencies, the annual appreciation speed of RMB RER (without considering the economic growth status of countries and areas) ranks third and should not be deemed "too slow." However, considering economic growth status (given China's fast economic growth), RMB RER appreciation speed ranks at the middle (when 2005–2010 is used) or near the bottom (when 1994–2010 is used). Thus, RMB RER appreciation is indeed a bit slow.

3.2. Which speed of RMB appreciation is feasible in the future?

Having known the RMB RER appreciation speed in the past, we determine at which speed the RMB should appreciate in the future. Instead of giving a subjective appreciation speed, we analyze which of China's experiences is more feasible. In Section 3.1, we have presented the RMB RER appreciation speed calculated for two periods, 1994–2010 and 2005–2010. In this section, we first calculate the (compound) annual growth rates of RER, NER, GDPP, and GDP in 1994–2010 and 2005–2010. Separate results are listed under the titles "1994–2010 scenario" and "2005–2010 scenario" in Table 3. Then we use each annual growth rate to forecast corresponding values from 2011 to 2022. For example, the annual RER growth rate in 1994–2010 was 3.2%, the actual RER value in 2010 was 58.3, the forecasted RER value in 2011 is 60.2 [58.3×(1+3.2%)], and that in 2012 is 62.1 [$58.3\times(1+3.2\%)^2$].

Table 3

Forecasting of exchange rates and GDPs in 2011–2022 for China based on 1994–2010 and 2005–2010 scenarios

	1994–2010 scenario					2005–2010 scenario			
	RER (US=100) (At 3.2%)	NER (yuan/US$) (At -1.5%)	GDPP (US=100) (At 10.9%)	GDP (US=100) (At 10.7%)		RER (US=100) (At 6.7%)	NER (yuan/US$) (At -3.7%)	GDPP (US=100) (At 18.1%)	GDP (US=100) (At 17.8%)
2010	58.3	6.8	9.4	40.6	2010	58.3	6.8	9.4	40.6
2011	60.2	6.7	10.4	44.9	2011	62.2	6.5	11.1	47.8
2012	62.1	6.6	11.6	49.8	2012	66.4	6.3	13.1	56.3
2013	64.1	6.5	12.8	55.1	2013	70.8	6.1	15.5	66.4
2014	66.1	6.4	14.2	61.0	2014	75.6	5.8	18.3	78.2
2015	68.2	6.3	15.8	67.5	2015	80.6	5.6	21.6	92.1
2016	70.4	6.2	17.5	74.7	2016	86.0	5.4	25.5	108.5
2017	72.7	6.1	19.4	82.7	2017	91.8	5.2	30.1	127.8
2018	75.0	6.0	21.5	91.6	2018	97.9	5.0	35.6	150.6
2019	77.4	5.9	23.9	101.4	2019	104.5	4.8	42.0	177.4
2020	79.9	5.8	26.5	112.2	2020	111.5	4.7	49.6	208.9
2021	82.4	5.8	29.3	124.2	2021	119.0	4.5	58.6	246.1
2022	85.1	5.7	32.5	137.5	2022	127.0	4.3	69.2	289.9

Notes: Values in 2010 are actual while those in 2011–2022 are forecasted. GDPP and GDP are originally measured by current US dollar and then converted to the indexes.

Source: WDI and the author's calculation.

The annual growth rates in 1994–2010 and 2005–2010 are different, so the forecast results based on these two scenarios are also very different. According to the 1994–2010 scenario, the annual growth rates of RMB RER, RMB NER, China's GDPP, and China's GDP are 3.2%, -1.5% (NER appreciates by 1.5% per year), 10.9%, and 10.7%, respectively. At such annual growth rates, by 2022, the RER will be 85.1 (the price level of China will be 85.1% that of the US), the NER will be 5.7 yuan per US dollar, China's GDPP will be about one third that of the US, and China's GDP will be 137.5% that of the US. According to the 2005–2010 scenario, the annual growth rates of RMB RER, RMB NER, China's GDPP, and China's GDP are 6.7%, -3.7%, 18.1%, and 17.8%, respectively.[6] By 2022, the RMB RER will be 127 (China's price level will be 1.27 times that of the US), NER will be nearly 4 yuan per US dollar, China's GDPP will be about 70% that of the US, and China's GDP will be about three times (289.9%) that of the US.

Given the different forecast results, which results are more reliable? From the view of actual economic status, the forecast results based on the 1994–2010 scenario are more reliable.

(1) On RER. The 1994–2010 scenario gives an annual RER growth rate of RMB (3.2%) that is a bit smaller than that of the Japanese yen (3.5%) and Korean won (3.6%) and greater than that of Taiwan dollar (1.9) and Singapore dollar (1.6%). Zhang and Fung (2006) concluded that RMB appreciation will bring a serious negative effect on China, a reduction in output that can potentially lead to a liquidity trap. Xu (2008) reviewed Taiwan's experience of currency appreciation and found that Taiwan dollar appreciation caused the painful short-run consequences of declining export production and employment. To overcome these difficulties, Taiwan introduced many changes to its economic structure. China can hardly handle a great challenge (given the annual RMB appreciation speed of 3.2% versus Taiwan dollar's 1.9%) more freely compared with Taiwan, whose economy is more flexible and robust than China's. In addition, the appreciation of the Japanese yen at a rate of 3.5%, especially after 1985 (the RER appreciated at an annual rate of 8% in 1985–1991), is often viewed as a typical unsuccessful example.

[6] Such higher annual growth rates of GDPP and GDP in the period 2005–2010, about 18%, are caused by two factors: China's relatively faster economic growth compared to the US and the high degree of RMB NER appreciation, which is a more important factor.

Considering the experiences of Taiwan and Japan, an appreciation speed of 3.2% is already enough, perhaps more than enough, for China to afford. Furthermore, an appreciation speed of 6.7% (from the 2005–2010 scenario), which is nearly twice that of the Japanese yen and more than thrice that of Taiwan dollar, seems quite unfeasible.

(2) On GDP. The 1994–2010 scenario gives an annual GDP growth rate of 10.7%, at which China's GDP will be slightly greater than that of the US after 2020 (137.5% that of the US by 2022). Meanwhile, the 2005–2010 scenario gives a startling rate of 17.8% per year, at which China's GDP will be nearly three times (289.9%) that of the US by 2022. Possibly, after ten years, China's GDP will surpass that of the US. However, China's GDP being nearly thrice that of the US by then is incredible, given that China's future economic growth will be slower after its thirty-year period of fast growth and that its future deep economic reform will be more difficult than ever. The annual GDP growth rate of 17.8% is obviously unreachable, indicating that the 2005–2010 scenario is unrealistic.

Our analysis shows that an annual RMB RER growth rate of 3.2% obtained from the 1994–2010 scenario is more realistic than the 6.7% obtained from the 2005–2010 scenario, given that four comparable Asian currencies have an RER appreciation speed around 3.2% (Korean won's 3.6% and Japanese yen's 3.5% above this value, and Taiwan dollar's 1.9% and Singapore dollar's 1.6% below this value). Therefore, an appreciation speed of 3.2% should be mainly considered by China's policymakers in future exchange rate level adjustment. Although this annual appreciation speed appears a bit slow relative to China's fast economic growth (see Section 3.1), it is very feasible considering China's lagging and slowly evolving economic structure.

In Section 2.2, we have known that, in 2010, the RMB RER was 58.3, its equilibrium value was 79.7, and its misalignment was 36.7%. In this section, we have determined that the preferred annual appreciation speed of RMB RER is 3.2%, at which the RMB RER will be 79.9 (roughly equal to the equilibrium value of 79.7) by 2020. In other words, the undervaluation of RMB RER in 2010, if adjusted at an appreciation speed of 3.2% per year, can be corrected by 2020.

4. Path of RMB appreciation

Having discussed appreciation speed, we now turn to the second issue, the path of RMB RER appreciation. We follow Frankel (2005) and Xu (2009) in analyzing the path of RMB RER appreciation from the two components of RER: NER and relative price level.

4.1. Path of RMB appreciation in the past and an international comparison

According to Eq. (1), changes in *RER* can be divided into two parts: change in bilateral *NER* and change in relative price level (P/P^*). All variables in Eqs. (5)–(7) have the same meanings as in Eq. (1).

At time 0: $$RER_0 = \frac{P_0 / P_0^*}{NER_0} \Rightarrow \log(RER_0) = \log(P_0 / P_0^*) - \log(NER_0) \qquad (5)$$

At time t: $$RER_t = \frac{P_t / P_t^*}{NER_t} \Rightarrow \log(RER_t) = \log(P_t / P_t^*) - \log(NER_t) \qquad (6)$$

The difference in log(*RER*) from time 0 to time t can be written as:

$$\begin{aligned}\log(RER_t) - \log(RER_0) &= [\log(P_t / P_t^*) - \log(P_0 / P_0^*)] - [\log(NER_t) - \log(RER_0)] \\ &= [\log(P_t / P_0) - \log(P_t^* / P_0^*)] - [\log(NER_t) - \log(RER_0)] \qquad (7)\end{aligned}$$

A variable's percent change is roughly equal to its natural logarithm difference, $(x_t-x_0)/x_0 \approx \log x_t - \log x_0$, so the percent change in *RER*, $(RER_t-RER_0)/RER_0$, can be measured by the difference of its natural logarithms, $\log(RER_t)-\log(RER_0)$. The same concept can be applied to P, P^* and *NER*. The difference in log(*RER*) from time 0 to time t can be decomposed into two components, $[\log(P_t /P_0)$ - $(\log(P_t^*/P_0^*)]$ and $-[\log(NER_t)$ - $\log(NER_0)]$, whose contributions can be measured by two ratios, $[\log(P_t/P_0)-(\log(P_t^*/P_0^*)]/[\log(RER_t)-\log(RER_0)]$ and $-[\log(NER_t)-\log(NER_0)]/[\log(RER_t)-\log(RER_0)]$, respectively. From the two ratios, we can determine how changes in relative price level (P/P^*) and NER contribute to changes in RER. The decomposed RER changes for eighteen countries and areas are calculated and given in Table 4. The countries and areas are sequenced by each NER's contribution to its RER. Considering the table and given the definitions of RER and NER in Eq. (1), a positive value of $-[\log(NER_t)-\log(NER_0)]/[\log(RER_t)-\log(RER_0)]$ means that NER has a positive effect on its RER (when NER appreciates, its RER also appreciates). In addition, the sum of $-[\log(NER_t)-\log(NER_0)]/[\log(RER_t)-\log(RER_0)]$ and $[\log(P_t/P_0)-(\log(P_t^*/P_0^*)]/[\log(RER_t)-\log(RER_0)]$ is 100%, as seen from Eq. (7).

Table 4
Decomposition of RERs for eighteen countries and areas

Country and area	Period: first year last year	RER_0 RER_t	$log(RER_t)$- $log(RER_0)$	NER_0 NER_t	$log(NER_t)$- $log(NER_0)$	$-[log(NER_t)$- $log(NER_0)]$ $/[log(RER_t)$- $log(RER_0)]$	$[log(P_t/P_0)$- $(log(P_t^*/P_0^*)]$ $/[log(RER_t)$- $log(RER_0)]$
Germany	1970 1992	71.1 120.2	0.525	1.87 0.80	-0.852	162.2%	-62.2%
Singapore	1965 1996	55.1 91.3	0.505	3.06 1.41	-0.775	153.5%	-53.5%
Japan	1950 1991	30.8 128.5	1.429	361 135	-0.986	69.0%	31.0%
Taiwan	1965 1996	43.8 78.4	0.584	40.0 27.5	-0.376	64.5%	35.5%
$China_{WDI}$	2005 2010	42.1 58.3	0.326	8.19 6.77	-0.190	58.5%	41.5%
$China_{PWT}$	2005 2009	37.2 48.9	0.275	8.19 6.83	-0.182	66.1%	33.9%
Netherland	1951 1975	42.3 96.8	0.828	1.72 1.15	-0.407	49.2%	50.8%
$China_{WDI}$	1994 2010	35.0 58.3	0.510	8.62 6.77	-0.242	47.3%	52.7%
$China_{PWT}$	1994 2009	29.8 48.9	0.496	8.62 6.83	-0.233	46.9%	53.1%
Thailand	1985 1996	39.4 51.0	0.259	27.2 25.3	-0.069	26.7%	73.3%
Norway	1953 1982	62.9 104.1	0.504	7.14 6.45	-0.101	20.1%	79.9%
Sweden	1952 1964	74.9 86.0	0.138	5.17 5.17	0.000	-0.1%	100.1%
Russia	1999 2009	20.7 62.2	1.103	24.6 28.8	0.156	-14.2%	114.2%
Finland	1959 1989	67.5 131.9	0.670	0.54 0.72	0.293	-43.8%	143.8%
Spain	1953 1975	43.2 65.2	0.412	0.24 0.35	0.370	-90.0%	190.0%
Romania	1999 2009	32.7 64.9	0.683	1.53 2.94	0.651	-95.3%	195.3%
Korea	1965 1996	26.8 81.2	1.107	266 805	1.105	-99.9%	199.9%
Hongkong	1960 1993	68.1 91.8	0.299	5.71 7.74	0.303	-101.4%	201.4%
Poland	1991 2009	39.8 66.8	0.517	1.06 2.85	0.991	-191.7%	291.7%
Italy	1952 1982	47.6 67.1	0.343	0.32 0.70	0.774	-225.9%	325.9%
France	1951 1982	74.5 87.3	0.158	0.53 1.00	0.630	-398.5%	498.5%

Notes: RER is defined by Eq. (1), with US=100 in each year. NER is expressed in national currency units per US dollar.
Source: WDI (only for data on $China_{WDI}$), PWT 7.0, and author's calculation.

Table 4 presents various RER appreciation paths for the listed countries and areas. There are three kinds of paths as discussed below.

(1) The first kind includes the cases of Germany and Singapore. Each RER appreciation was realized totally from NER, with relative price level giving a negative effect. In their periods, each country's NER appreciated as relative price level decreased. The NER appreciated too much that it not only offset all the negative effect of the relative price level but also led to RER appreciation.

(2) The second kind includes the cases of Japan, Taiwan, China, Netherlands, Thailand, and Norway. Each RER appreciation was realized partly from NER and partly from relative price level. However, contributions from changes in RER and relative price level differ. For Japan and Taiwan, each RER appreciation was realized mostly (about two-thirds) from NER appreciation and a little (about a third) from an increase in relative price level. For Netherlands, RER appreciation was partly (half) realized from NER appreciation and partly (half) from an increase in relative price level. For Thailand and Norway, however, each RER appreciation was realized a little (about a quarter) from NER appreciation and mostly (about three-quarters) from an increase in relative price level.

For China, in the period 2005–2010 or 2005–2009, NER appreciation accounted for about 60% of RER appreciation and the increase in relative price level accounted for about 40% (similar to the cases of Japan and Taiwan). In the period 1994–2010 or 1994–2009, about 50% of RER appreciation was accounted for by NER appreciation and the other half by the increase in relative price level (similar to the case of Netherlands).

(3) The cases of all the other countries belong to the third kind. Each RER appreciation was totally realized from the increase in relative price level because NER depreciated during the period. However, the cases are different. For Sweden, Russia, and

Finland, the negative effect of NER was weak, less than 50%. For Spain, Romania, Korea, and Hong Kong, the negative effect of NER was about 100%. Furthermore, for Poland, Italy, and France, the negative effect of NER was strikingly about 200% or even more.

China is free to choose a path from these various appreciation paths. However, as seen from experience (both periods in the study), China has chosen the path of realizing RER appreciation partly from NER appreciation and partly from an increase in relative price level. In addition, the contribution of RMB NER to RMB RER appreciation had increased in the latest years, from smaller than 50% in 1994–2010 to about 60% in 2005–2010, an obvious result of US pressure.

4.2. Which path of RMB appreciation is desirable in the future?

Having known that China has chosen an appreciation path through both NER appreciation and an increase in relative price level, we wonder whether the path is expected by the US and China. We analyze this issue from the effect of the appreciation path on the US and China. Although the effects of RMB RER appreciation are comprehensive, with effects on export, import, employment, investment, and consumption, the most direct and pressing effect (especially from the view of government) is on export. Hence, we illustrate the effect of RMB appreciation on export.

Following Frenkel and Ros (2006) and Thorbecke and Zhang (2009), we use RER and the foreign country's income to explain the effect of RER effect on bilateral export. To increase the sample size and reflect the current situation, we use monthly data. Monthly data on the relative price level (P/P^*) of RER and GDP of China cannot be obtained, so we use consumer price index with fixed base and industrial production as proxies, respectively. NER is expressed in RMB yuan units per US dollar. All data are from IMF's International Financial Statistics (IFS) and DOTS online databases. Although other data can be traced back to the early 1980s, the monthly consumer price indexes and industrial production data of China are only available after 1987 and after 1994, respectively. Thus, the actual samples used in the regressions, Eq. (7) and (8), have to be reduced accordingly.

The ADF unit root test reveals that all the variables depict I(1) behavior in each group. Furthermore, Johansen test proves that there is at least one cointegration relationship between the variables in each group. Ordinary least squares give the regression results in Eqs. (7) and (8). Equation (7) describes how China's export (*EXPCH*) is affected by US industrial production (*INDUS*) and the RMB RER, in terms of its three components, NER, China's consumer price index (*CPICH*), and US consumer price index (*CPIUS*). Similarly, Eq. (8) describes how US export (*EXPUS*) is affected by China's industrial production (*INDCH*) and the RMB RER. The values in parentheses below the coefficients are their t-statistics (second line) and associated p-values (third line), which are calculated using Newey–West HAC standard errors and covariance.

$$\log(EXPCH) = \underset{\substack{(-61.69)\\(0.00)}}{-26.01} + \underset{\substack{(4.60)\\(0.00)}}{1.05}\log(INDUS) + \underset{\substack{(2.32)\\(0.02)}}{0.35}\log(NER) \underset{\substack{(-1.89)\\(0.06)}}{-0.36}\log(CPICH) + \underset{\substack{(22.74)\\(0.00)}}{6.92}\log(CPIUS) \quad (7)$$

Adjusted R^2=0.97, sample=January 1987 to October 2011, observations=298

$$\log(EXPUS) = \underset{\substack{(-1.68)\\(0.09)}}{-5.96} + \underset{\substack{(2.28)\\(0.02)}}{0.37}\log(INDCH) - \underset{\substack{(-2.40)\\(0.02)}}{0.99}\log(NER) \underset{\substack{(-4.16)\\(0.00)}}{-1.23}\log(CPICH) + \underset{\substack{(5.65)\\(0.00)}}{4.56}\log(CPIUS) \quad (8)$$

Adjusted R^2=0.95, sample=January 1994 to September 2011, observations=213

Eqs. (7) and (8) show that RMB NER appreciation will lead to a decrease in China's export (1% *NER* appreciation will lead to a 0.35% decrease in China's export, given other variables unchanged, following the same) but to an increase in US export (1% *NER* appreciation will lead to a 0.99% increase in US export), which is consistent with economic theory. An increase in China's price level will lead to a decrease in China's export (1% increase in *CPICH* will lead to a 0.36% decrease in China's export) and to a decrease in US export (1% increase in *CPICH* will lead to a 1.23% decrease in US export). There are two explanations. First, when China's price level increases, the production cost of China's export enterprises will also increase. This will subsequently reduce the output of these enterprises, including their export. Second, when China's price level increases, the dispensable income of local citizens will decrease, leading them to reduce their consumption, including their consumption of import goods from the US.

In terms of policy implication, for China's export [Eq. (7)], given that the coefficient of log(*NER*) is 0.35 and that of log(*CPICH*) is -0.36 (significant at 10% level), NER appreciation and an increase in price level have roughly an equal negative effect on export. Therefore, the effects of any choice of RMB RER appreciation path, whether totally from NER appreciation, partly from NER appreciation and partly from an increase in relative price level, or totally from an increase in relative price level, on China's export are the same. However, if NER appreciation coincides with an increase in relative price level, RER will appreciate at a compound rate, resulting in a greater negative effect on the economy. This is the case in the period from November 2006 to July 2008, when RMB NER appreciated by 13.1%, China's CPI increased by 16.2%, and US CPI increased by 9.2%, all of which gave an RER appreciation of 20.1% (13.1%+16.2%-9.2%). This high degree of RER appreciation, through both NER and relative price level channels, was one of the main factors that forced many of China's offshore export enterprises to close shops at that time. Had China controlled the increase in its price level at a smaller rate at that time, the negative effect of RER appreciation would have been greatly reduced. For example, had China's CPI been kept the same as that of the US, RER appreciation would have been reduced by 7% (16.2%-9.2%). In this light, Germany's case is a good example. Germany experienced a high degree of NER appreciation (from 1.87 D-mark per US dollar in 1970 to 0.8 D-mark per US dollar in 1992) but controlled its price level well (the relative price level had a negative effect on its RER appreciation). Thus, in RMB RER appreciation, China's policymakers should focus on controlling the price level instead of always resisting US pressure on

RMB appreciation.[7] As long as China's policymakers control the price level well, the negative effects of RMB RER appreciation will not be as catastrophic as imagined.

For US export [Eq. (8)], given that the coefficient of log(*NER*) is -0.99 and that of log(*CPICH*) is -1.23, RMB NER appreciation (increase in China's price level) has a positive (negative) effect on US export. These two different effects suggest that realizing RMB RER appreciation totally from NER is preferred by the US. In other words, if RMB RER appreciation is realized partly or totally from an increase in relative price level, US export will be harmed.

Considering benefits to both China and the US, our analysis shows that the desirable path of RMB RER appreciation is totally from NER. Meanwhile, the increase in price level should be slow. The appreciation of NER and slow increase in price level (at a smaller rate, even smaller than that of the US) will not only help US export but also reduce the negative effect of NER appreciation on China. The above analysis combined with findings in Section 3 suggest that the recommended annual RMB RER appreciation speed of 3.2% should be realized totally from NER, as in the cases of Germany and Singapore (see Table 4), rather than partly from NER and partly from the relative price level as China earlier experienced.

5. Conclusion

This study has examined three issues on RMB RER (relative to the US dollar): how it was undervalued, which speed of appreciation is feasible, and which path of appreciation is desirable. The examination of these issues adds new understanding to the current debate on RMB appreciation.

Although there are many models used in assessing currency valuation, the Penn effect model, which is broadly used, is most appropriate for this study. Using the panel data Penn effect model, we find that in 1980-1991 the RMB was all overvalued and showed a decline trend. But it turned to be undervalued in 1992-2010. In latest years, the degree of undervaluation increased from 15% in 2002 to greater than 30% in 2005–2010. In 2010, the RMB was undervalued by 36.7%. The change in RMB misalignment during this period can be explained mainly by changes in RMB RER and China's economic growth.

To understand the speed of RMB RER appreciation comprehensively, we calculate the annual appreciation speed of RMB and 17 other currencies of countries and areas in an economic development stage similar to that of China. The annual appreciation speed of RMB RER was 6.7% in 2005–2010 and 3.2% in 1994–2010, which is in the front row compared with that of the other seventeen currencies. However, considering China's fast economic growth, the coefficient of the Penn effect model shows that RMB appreciation is a bit slow. A forecast of future RER and GDP based on the 1994–2010 and 2005–2010 scenarios shows that the annual appreciation speed in 1994–2010 is more reliable than that in 2005–2010. Comparison shows that four other Asian currencies also had an RER appreciation speed of around 3.2% during their similar periods, thereby supporting the recommendation that China should make this rate an important reference in future RMB RER appreciation. At this rate, the RMB's undervaluation in 2010 can be corrected by 2020.

Lastly, we calculate the contributions of changes in NER and relative price level to changes in RER for all eighteen chosen currencies. Globally, there are three kinds of RER appreciation paths: totally through NER, totally through relative price level, and partly through NER and partly through relative price level. For RMB, past RER appreciation was realized partly from NER appreciation and partly from an increase in relative price level, with the contribution of NER increasing in the latest years. Econometric analysis shows that RMB NER appreciation will have a negative effect on China's export and a positive effect on the US's export, whereas an increase in relative price level will have a negative effect on the export of both China and the US. Given the different effects in the two components of RMB RER, the desirable path of its future appreciation is totally from appreciating NER while making the increase in price level slow. This appreciation path is in the interest of both China and the US. In addition, China's policymakers should improve their ability to manage the price level. If China's price level is effectively controlled, the effects of RMB appreciation will not be as disastrous as imagined.

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