Weighted Average Relative Price (WARP):

A Supplement to Standard Real Effective Exchange Rates (REERs)[1]

Charles Thomas and Jaime Marquez
(Federal Reserve Board of Governors)

Abstract

This paper describes a weighted average relative price (WARP) for the United States. The staff in the International Finance Division of the Federal Reserve Board has found it to be a useful supplement to Board's standard real effective exchange rate (REER) measures. The idea behind the WARP is very simple: It attempts to measure the level of US prices relative to the prices of those countries that either trade directly with the United States or compete against US exporters in third markets. We review how REERs and the WARP are constructed and discuss why the WARP will reflect an interaction between differences in price levels and changing trade shares that REERs cannot capture. We show that for the United States there is a significant difference between the secular movement in the REER and the WARP. We also discuss some work done with the WARP and how WARP relates to measures of competitiveness.

Kewords: Real Effective Exchange Rates, Purchasing Power Parity, International Comparison Project, Competitiveness.

JEL classification: C43, C82, F41.

[1] This paper was prepared for the 6th Irving Fisher Committee Conference on "Statistical Issues and Activities in a Changing Environment," held in Basel on August 28-29, 2012. We are grateful to Vivian Wong for research assistance. The views in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System or of any other person associated with the Federal Reserve System.

1 Introduction and Summary

This paper describes our weighted average relative price (WARP).[2] The staff in the International Finance Division of the Federal Reserve Board has found it to be a useful supplement to the Board's standard real effective exchange rate (REER) measures. The idea behind the WARP is very simple: It attempts to measure the level of US prices relative to the prices of those countries that either trade directly with the United States or compete against US exporters in third markets.[3] Later we describe in detail how this measure differs from standard real effective exchange rates (REERs), but first a little motivation is useful.

As shown in Figure 1, between 1970 and 1985, the share of US trade that was with emerging market economies (EMEs) stayed fairly steady at about 25 per cent. Starting in the mid-eighties, as these economies became more integrated in the global trade network, their share in US trade started to grow to where it is now over 50 per cent.

Since many EMEs had lower cost structures than the developed economies, this meant that a larger share of US and world trade was with relatively low-cost producers. We could see the effects of this on import prices and the pattern of trade, and it clearly had implications for US external balances and employment. However, the standard REERs, were not signalling any secular change in real exchange rates. There was no signal because the REERs are not designed to pick up this kind of secular change. The world was seeing a shift in the location of productive capacity. As a first order event, this was a change in quantities, not prices, and the REERs are designed to pick up only price changes. The point of the WARP is to capture the way shifting quantities (or productive capacities) interact with established differences in price levels to affect competitiveness.

In the next section we review how REERs are constructed and contrast them with the WARP. Since the WARP uses the purchasing power parity (PPP) exchange rates computed by the World Bank's International Comparison Project (ICP), this requires a bit of a detour into how PPPs are put together. We then compare the WARP to standard REERs and show that indeed it has a secular trend that the REERs do not. The note closes with a few examples of where we have used the WARP and discusses how it relates to notions of competitiveness.

2 REERs vs. WARP: Their construction

2.1 REERs

All REERs for the United States start with a set of bilateral market exchange rates against the dollar E(j/$,t). As given in equation (1), these are then adjusted for relative price movements in the two economies, typically using the ratio of a US price index to a price index for country *j*:

$$(1) \quad q_{j,t} = \frac{PI_{us,t}}{PI_{j,t}} \cdot E_{\frac{j}{\$},t}$$

These $q_{j,t}$ are bilateral real exchange rates against the dollar and an increase represents a real appreciation of the US dollar.

[2] See Thomas et al. (2008).

[3] We are by no means the first to think of this or to implement it. Early and excellent work on this was done at the BIS by Turner and Van't dack (1993).

Of course, the price indexes (the PIs) are just that, price indexes, so their ratio in a given time period has no intrinsic meaning. The information content in the ratio is in how it moves over time.

From these bilateral measures, the REER is usually constructed as a chain index with time-varying trade weights, as follows:

(2) $$\frac{Q_t^{CR}}{Q_{t-1}^{CR}} = \prod_{j=1}^{J} \left(\frac{q_{j,t}}{q_{j,t-1}}\right)^{\omega_{j,t}}$$

where $\omega_{j,t}$ is a simple trade weight or some other measure of the relative importance of country *j* in our trade at time *t* and *J* is the number of countries. The level of Q_t^{CR} is set equal to 100 in some arbitrary period and the other periods are solved for recursively.

By using period-to-period ratio changes in the $q_{j,t}$, we get around the fact that the levels of the price indexes, and hence the *q*'s, have no intrinsic meaning. We only use the information content in their changes over a given period—say a month or a quarter. Of course there are many price indexes one can choose from—CPIs, PPIs, unit labour costs, etc., and there are many ways to construct the trade weights. Given these choices there are many ways to construct chained REERs.

One can also construct a REER by aggregating levels, that is, without chaining. For example, we could set all price indexes, $PI_{j,t}$, including those for the United States, to equal one in some base period, call it *z*; index the exchange rates to one in the same period; and then construct the REER as an arithmetic or geometric average of the ratios of the normalized US index to the normalized foreign indexes. The geometric one is more common and is constructed via (3)-(5):

(3) $$PI'_{j,t} = \frac{PI_{j,t}}{PI_{j,z}}, \qquad E'_{\frac{j}{\$},t} = \frac{E_{\frac{j}{\$},t}}{E_{\frac{j}{\$},z}}$$

(4) $$q'_{j,t} = \frac{PI'_{US,t}}{PI'_{j,z}} \cdot E'_{\frac{j}{\$},t}$$

(5) $$Q_t^{LR} = \prod_{j=1}^{J} \left(q'_{j,t}\right)^{\omega_{j,t}}$$

These measures give the weighted change in the bilateral real rates since the base period.

There are two problems with these: First, the value of Q_t^{LR} depends on what base period, *z*, you choose. So you need a good reason to pick one base period over another. Second, it still does not fully capture the quantity effects discussed earlier, unless the low-cost producers became low-cost sometime after the base period.

To see why none of these REERs address the quantity effect, we run the following thought experiment: Suppose the United States trades with many countries, some with relatively high prices and some with relatively low prices. To keep things simple we suppose inflation rates are the same everywhere and nominal exchange rates are fixed. So all the $q_{j,t}$ are constant during our experiment. Now, as happened in the 1980s, we suppose the low-price economies grow faster than the rest, greatly expand their productive capacities, and start producing more goods for international trade.

What happens to the REERs? The chained REERs do not move. The weights change, but because there is no period-to-period change in the bilateral price ratios, the aggregate measure does not change. What about the REERs constructed in levels via equations (3)-(5)? These aggregates may move as the weights move because the ratios that we are aggregating need not all be equal to one over this period. But the amount and direction by which the aggregates move will depend entirely on what happened between the base period, *z*, (when all the $q'_{j,t}$ ratios were set to one) and the starting date of our thought experiment.

2.2 WARP

As do the REERs, the WARP starts with market exchange rates and measures of US prices and foreign prices. The difference in the WARP is that it uses measures of the US price *level* relative to the foreign price *level* and not relative price *indexes*. These measures of relative price levels come from the purchasing power parity (PPP) exchange rates constructed by the International Comparison Project (ICP). Most economists have some familiarity with PPPs, but given the central role they play in WARP, we take a detour here to describe how they are constructed.

How the PPPs are constructed

The ICP first collects spending and price data for a large set of goods and services that are as comparable as possible across countries. In greatly simplified terms, it then sets up a large set of simultaneous equations.[4]

For every product *n* that it collects data on, it posits that there is an average "world price," π_n. This world price is in terms of a fictional currency called the "international dollar." The world price is an average of individual countries' prices for good *n*, where the weight given to each country is its share in the world's consumption of that good. If there are N goods in the world, then there N equations that look like this:

$$(6) \quad \pi_n = \sum_{j=1}^{J} \left(\frac{P_{n,j}}{PPP_j}\right) \cdot \left(\frac{Y_{n,j}}{\sum_j^J (Y_{n,j})}\right) \quad \text{n=1…N}$$

Of course to do this we needed an exchange rate to convert country *j*'s local currency into international dollars. These are the PPP exchange rates. Where do these PPPs come from? For each country *j*, its PPP exchange rate is such that if one takes the nominal income of that country in its local currency and converts that income into international dollars at the PPP, then the value of that income in international dollars would be just sufficient to buy the country's expenditure basket at world prices. That is:

$$(7) \quad \sum_{n=1}^{N} \frac{P_{n,j} \cdot Y_{n,j}}{PPP_j} = \sum_{n=1}^{N} \left(\pi_n \cdot Y_{n,j}\right) \text{ and if we rearrange this, we have}$$

$$(8) \quad PPP_j = \frac{\sum_{n=1}^{N} \left(P_{n,j} \cdot Y_{n,j}\right)}{\sum_{n=1}^{N} \left(\pi_n \cdot Y_{n,j}\right)} \quad \text{j=1…J}$$

Thus the PPP is a weighted average of local currency prices divided by a weighted average of world prices (in international dollars) where the weights are country *j*'s expenditure shares.

This system has J+N equations and just as many unknowns. However, only J+N-1 of them are independent.[5] To remove this indeterminacy, the ICP sets the exchange rate between the US dollar and the international dollar to one.[6] This means the PPP for the United States is one and we have

$$(9) \quad 1 = \frac{\sum_{n=1}^{N} \left(P_{n,US} \cdot Y_{n,US}\right)}{\sum_{n=1}^{N} \left(\pi_n \cdot Y_{n,US}\right)} .$$

If we divide (9) by (8) and multiply both sides by country j's market exchange rate against the US dollar we have

---

[4] Our presentation follows closely that of Gulde and Schulze-Ghattas (1993); see Kravis, Heston, Summers (1978, 1982) for additional details.

[5] To see this we note that for any solution we can multiply all the international prices by an arbitrary constant and divide the PPPs by that same constant and still have a solution for all the equations in (6) and (8).

[6] That the ICP chooses to eliminate the world price/exchange rate indeterminacy by setting the PPP for the US to one is convenient, but it in no way affects derived measures of relative prices or income.

(10) $$\frac{E_{\frac{j}{\$}}}{PPP_j} = \frac{\left(\frac{\sum_{n=1}^{N}(P_{n,US}\cdot Y_{n,US})}{\sum_{n=1}^{N}(\pi_n\cdot Y_{n,US})}\right)}{\left(\frac{\sum_{n=1}^{N}(P_{n,j}\cdot Y_{n,j})\left(\frac{1}{E_{\frac{j}{\$}}}\right)}{\sum_{n=1}^{N}(\pi_n\cdot Y_{n,j})}\right)}$$

Focusing on the right hand side of (10), we see the numerator is the ratio of US prices in dollars to world prices in international dollars. The denominator is the ratio of foreign prices—converted to dollars using the market exchange rate—to world prices in international dollars. This leaves us with the ratio of US prices to foreign prices when both are expressed in a common currency using market exchange rates.

Aggregating the relative price levels to WARP:

Given that we now have bilateral measures that capture the level of US prices relative to the level of foreign prices when both are expressed in a common currency (the left hand side of (10)), we just need to aggregate them to a measure of US prices relative to our trading partners' prices. For this, we use geometric aggregation as follows:

(11) $$q''_{\mathrm{j,t}} = \frac{1}{PPP_{j,t}} \cdot E_{\frac{j}{\$},t},$$

(12) $$Q_t^W = \prod_{j=1}^{J}\left(\mathrm{q}''_{\mathrm{j,t}}\right)^{\omega_{j,t}}$$

We note that the level of Q_t^W has a very natural interpretation as the ratio of US prices to foreign prices. Thus a value of 1.5 implies that US prices are 50 per cent higher than the average of our trading partners' prices.

3 REERs vs. WARP: Their behaviour over time

This section compares the movement of the WARP to several REERs over the past several decades. Before comparing the measures, it is useful to look at the movements of what goes into them. As noted earlier, and shown in Figure 1, the share of US trade done with emerging market economies (EMEs) has increased dramatically since the early 1980s.[7] This is one key requirement for there to be a difference between the WARP and the REERs. The other key requirement is that there be a significant difference in the price levels across our trading partners. Figure 2 illustrates that this second requirement is also fulfilled. The dashed blue line plots the ratio of US prices to the prices of our advanced foreign economy (AFE) trading partners. This ratio was near 1.3 in early 1985 when the dollar was at its peak, but has since been in the range of 1.1 to 0.9. That is, by this measure US prices were roughly 30 percent above our AFE trading partners' prices in 1985, but have since been roughly equal to theirs plus or minus 10 per cent. The solid green line shows the ratio of US prices to those of our emerging market economy (EME) trading partners. It has also moved with the large swings in the dollar, but it has generally been in the neighbourhood of 1.7, implying that US prices have been roughly 70 per cent higher than EME prices.

Figure 3 shows what happens when we put these pieces together. The solid green line is the WARP when it includes the prices of all our major trading partners. The other lines plot three standard REERs—the Federal Reserve Board's Broad Real Dollar (solid black), the

[7] The trade weights used throughout this paper are those constructed at the Federal Reserve Board for its Broad Real Exchange Rate Index and related measures. Their construction is described in Leahy (1998).

IMF's REER for the US dollar (dashed red) and the BIS's REER for the dollar (boxed blue). The three REERs have been re-indexed so they all equal the value of the WARP in 1994Q1—the first quarter for which we have an observation for the BIS measure.

There are two points to take away from this figure. The first is how closely the three REERs track each other over the period. Compared to the FRB's REER, the IMF's measure shows somewhat more appreciation of the dollar in the early 1980s, but since 1985 these two REERs have moved nearly in lock step. The same is true for the BIS measure. Since its start in 1994, it has moved almost exactly with other two REERs.

The second point, and the reason for writing this note, is that the WARP does not follow the other measures over the whole period. The WARP tracks the REERs fairly closely between 1986 and 1998, but starting in the late 1990s, the WARP shows much more real dollar appreciation. In fact, if we compare the latest value for the WARP with its value in the early 1990s, it shows a noticeable real appreciation. In contrast, the REERs show a noticeable depreciation over the same period.

We do not take the stand that the WARP is telling the 'true' story and the REERs are not. There is no reason to. Researchers have many measures to choose among and the choice of which one measure, or set of measures, to use will be determined by what is most useful for the question at hand. The WARP is designed to pick up a feature of the trade landscape that the REERs cannot, and it seems to do that. As such, at a minimum, we consider it a useful supplement to the REERs.

4 Applications

This section reports on some applications of the WARP. Since few others have been using the WARP, the section is embarrassingly self-referential. As noted above the idea of using PPPs to get at level price differences is not new to us; Turner and Van't dack (1993) discuss the idea. More recently Nickell (2005) uses a similar construct to investigate why UK inflation was so low in the early 2000's.

Our first applications focused on the implications of using WARP for modelling US international trade with an emphasis on the responsiveness of US trade to economic activity (see Thomas et al. 2008 and 2009a) and the response of import prices to changes in exchange rates (Thomas et al. 2009a). We found that using WARP confers a distinct advantage in terms of coefficient magnitudes and out-of-sample forecasts relative to the conventionally measured REER. For most work at the Federal Reserve Board the WARP has not displaced the standard REERs, but is being used alongside of them. This is the same approach taken by the IMF when it included the WARP in its 2012 Article IV consultation for the United States (IMF, 2012).

While it is clear that the REER and WARP are quite different for the United States, it is natural to ask if there is such a large difference for other countries. In a forthcoming volume from the World Bank (Thomas et al. 2011), we compute WARPs for many countries, compare them to their REERs, and then decompose the differences into the contributions from price level differences and changes in trade shares.

That study also uses disaggregate PPP data provided by the ICP to examine how sensitive such measures are to the inclusion of non-tradable goods and services. For 2005, when all goods and services prices are considered, the US WARP shows US prices to be more than 20 per cent above those of its trading partners. However, when we restrict ourselves to looking only at goods and services that are generally traded internationally, there is little difference between US prices and those of its trading partners. As discussed below, we do not view this as an argument for excluding non-tradables. Because we expect international trade to eliminate large differences in traded goods prices, we expect the fundamental drivers of competitiveness and trade to be largely determined by the prices of non-tradables.

Finally, recognizing the spectacular increase in China's participation in world trade, we looked at the behaviour of China's WARP in Thomas et al. (2009b, 2009c). As expected, we find that China's prices are indeed well below the average of its trading partners. However, we also find that China's WARP has been rising over the same time that China's growing participation in world trade has meant that it has been pushing up its trading partners' WARPs.

This China example illustrates an important difference between the WARPs and the REERs. With the REERs, as with bilateral exchange rates, if some currencies show an appreciation, some others must be showing a depreciation. The WARPs, do not have this property. As a developing country grows quickly its prices may rise faster than its trading partners', imparting an upward drift to the developing country's WARP. Yet, if the developing country's prices remain at a level below its trading partners', and the developing country's share in world trade increases, increased trade with this country can impart an upward drift to the WARPs of its trading partners. Thus it is possible for all WARPs to move in the same direction at once.

5 On competitiveness and final thoughts

This brings us to our last question regarding the WARPs: How do they relate to competitiveness? The point made just above argues for some caution in relating WARPs to competitiveness. Since all the WARPs could move up at once, we would be hard pressed to then say that everyone is becoming less competitive at the same time.

Aside from this possible anomaly, there are two more fundamental difficulties in relating WARPs to competitiveness. The first is finding a reasonable working definition of competitiveness. As Keynes (1925) noted almost a century ago, one cannot think of competitiveness in terms of the differences in traded goods prices (prices of "unsheltered" goods in his words) because trade by its nature tends to eliminate such differences. Max Cordon concluded a reasonable definition is in terms of the profitability of firms in the traded sectors (Corden, 1994).

Working with Corden's notion of competitiveness as profitability, we are then left with trying to map cross-country differences in general price structures (possibly for just non-traded goods and services) into cross-country differences in the cost structures for traded goods and services. Such a mapping requires measures of relative labour and capital productivity in the traded sectors. The WARPs do not include such productivity measures. Put differently, the WARPs provide a summary measure of relative price structures across countries. To read them directly in terms of competitiveness or relative cost structures one would have to assume that labour and capital productivity are equalized across countries. This is clearly not the case, so the WARPs cannot capture all that is needed to measure competitiveness.

So where does that leave us? The discussion relating WARP to competitiveness is meant to be cautionary. The WARP seems to be related to competitiveness, but we caution against using it, or any single simple measure, to quantify such a complex aspect of the economy. On a more positive note, the WARP does capture some important phenomena that are not well reflected in other measures and we have found it to be helpful in explaining some important macroeconomic phenomena. As such we consider WARP to be a useful addition, or supplement, to the more standard, widely used, REERs.

References and Selected Related Works

Chen, S. and M. Ravallion, 2008, "China is Poorer that we Thought, But No Less Successful in the Fight Against Poverty," World Bank Policy Research Working Paper, No. 4621.

Chinn, M., 2005, "A Primer on Real Effective Exchange Rates: Determinants, Overvaluation, Trade Flows and Competitive Devaluation," NBER Working Paper, No. 11521.

Corden, M., 1994, *Economic Policy, Exchange Rates, and the International System*, Chicago: University of Chicago Press.

Deaton, A. and A. Heston, 2008, "Understanding PPPs and PPP-based National Accounts," NBER Working Paper no. w14499.

Froot, K. and K. Rogoff, 1995, "Perspectives on PPP and Long-run Real Exchange Rates," in G. Grossman and K. Rogoff (eds.), *Handbook of International Economics*, vol 3., Amsterdam: North-Holland.

Gulde, A. M. and M. Schulze-Ghattas, 1993, "Purchasing Power Parity Based Weights for the World Economic Outlook," *World Economic Outlook*--December 1993, Washington DC: International Monetary Fund.

Heston, A., R. Summers and B. Aten, 2006, Penn World Table Version 6.2, Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania.

Hooper, P. and J. Richardson (eds.), 1991, *International Economic Transactions: Issues in Measurement and Empirical Research*, Chicago: University of Chicago Press.

International Monetary Fund, 2012, IMF Country Report No. 12/213: United States – 2012 Article IV Consultation. http://www.imf.org/external/pubs/ft/scr/2012/cr12213.pdf

Keynes, J. M., 1925, “The Committee on the Currency,” *The Economic Journal*, 138, 299-304.

Klau, M. and S. Fung, 2006, "The New BIS Effective Exchange Rate Indices," *BIS Quarterly Review*, March, 51-65.

Kravis, I. and R. Lipsey, 1990, "The International Comparison Program: Current Status and Problems," NBER Working Paper no. 3304.

Kravis, I., A. Heston, and R. Summers, 1978, *International Comparisons of Real Product and Purchasing Power*, Baltimore: Johns Hopkins University Press.

Kravis, I., A. Heston, and R. Summers, 1982, *World Product and Income: International Comparisons of Real Gross Product*, Baltimore: Johns Hopkins University Press.

Leahy, M., 1998, "New Summary Measures of the Foreign Exchange Value of the Dollar," *Federal Reserve Bulletin*, 811-18.

Lipsey, R., L. Molinary, and I. Kravis, 1990, "Measures of Prices and Price Competitiveness in International Trade in Manufactured Goods," NBER Working Paper, No. 3442.

Nickell, S. (2005): Why has inflation been so low since 1999?, Bank of England Quarterly Bulletin 45, Issue 1, 92-107.

Obstfeld, M. and K. Rogoff, 1996, Foundations of International Macroeconomics, Boston, MA: MIT Press.

Summers, R. and A. Heston, 1991, "The Penn World Table (Mark 5): An expanded Set of International Comparisons, 1950-1988," *Quarterly Journal of Economics*, 106, 327-368.

Taylor, M., 2003, "Purchasing Power Parity," *Review of International Economics*, 11, 436-452.

Thomas, C., J. Marquez, and S. Fahle, 2008, "Measuring U.S. International Relative Prices," Federal Reserve Board International Finance Discussion Paper, No. 917.

Thomas, C. and J. Marquez, 2009a, "Measurement Matters for Modeling U.S. Import Prices," *International Journal of Finance and Economics*, Vol. 14, 120-138. http://www3.interscience.wiley.com/cgi-bin/fulltext/120735479/PDFSTART .

Thomas, C., J. Marquez, and S. Fahle, 2009b, "Measures of International Relative Prices for China and the United States," *Pacific Economic Review*, Vo. 14, 376-397. http://www3.interscience.wiley.com/cgi-bin/fulltext/122522842/PDFSTART .

Thomas, C., J. Marquez, and S. Fahle, 2009c, "Measuring China's International Relative Prices," *ICP Bulletin* Vol. 6, No 1 (March), pp. 24-28 (World Bank). http://siteresources.worldbank.org/ICPINT/Resources/270056-1208272795236/ICP-newsletter_04-09_PressQuality-v4.pdf .

Thomas, C., J. Marquez, S. Fahle, and J. Coonan, 2011 (forthcoming), "International Relative Price Levels: Stylized Facts," with in *MEASURING THE SIZE OF THE WORLD ECONOMY: A Framework, Methodology and Results from the International Comparison Program (ICP,* World Bank).

Turner, P. and J. Van't dack, 1993, "Measuring International Price and Cost Competitiveness," BIS Economic Papers, No. 39.

World Bank, 2008, *Global Purchasing Power Parities and Real Expenditures: 2005 International Comparison Program*, Washington DC: World Bank.

Figure 1
Trade Shares

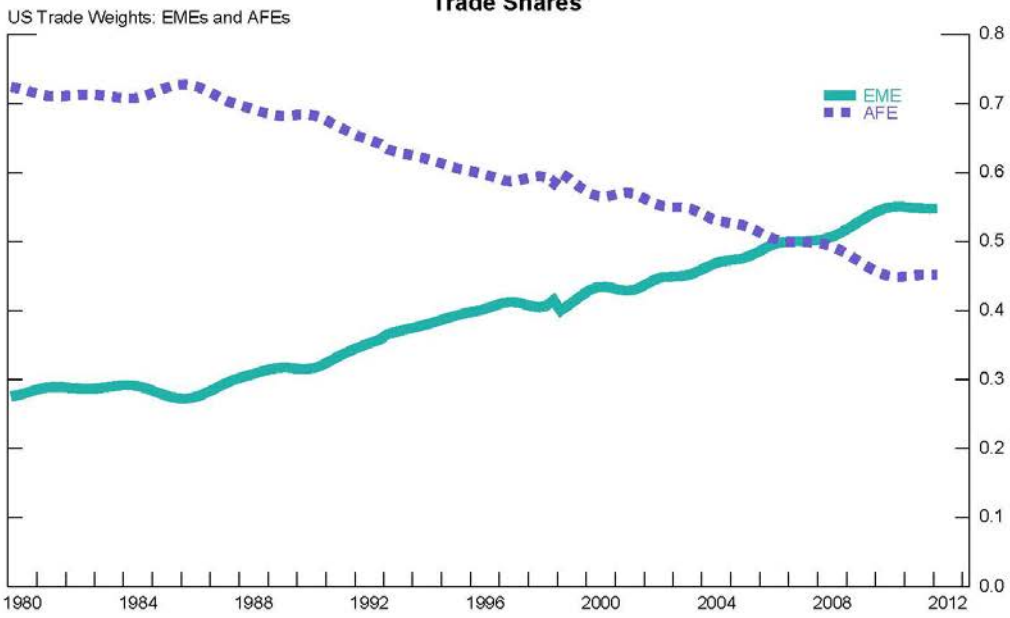


Figure 2
Relative Prices

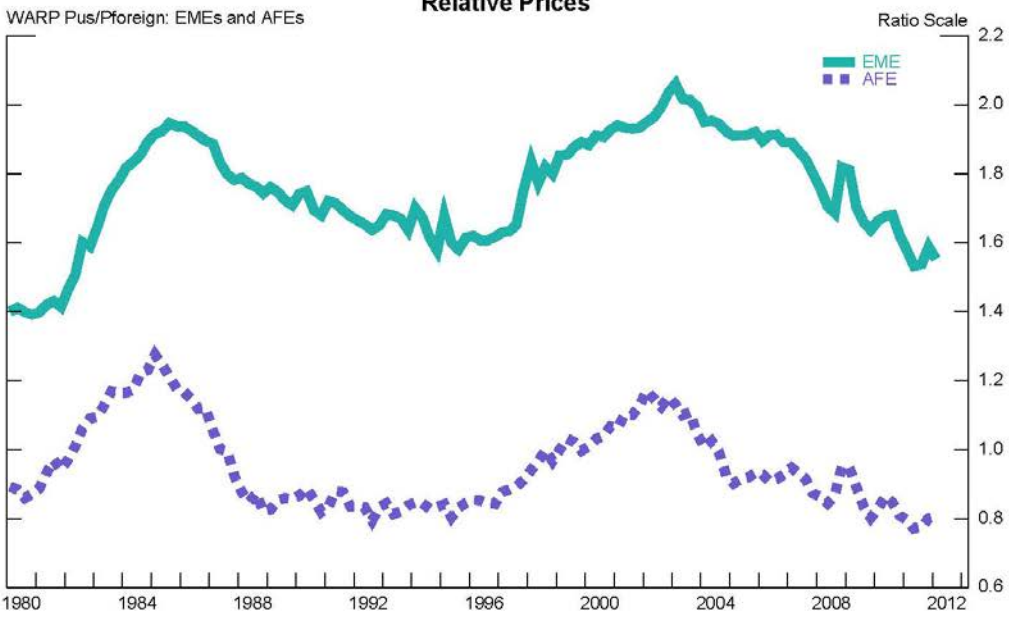
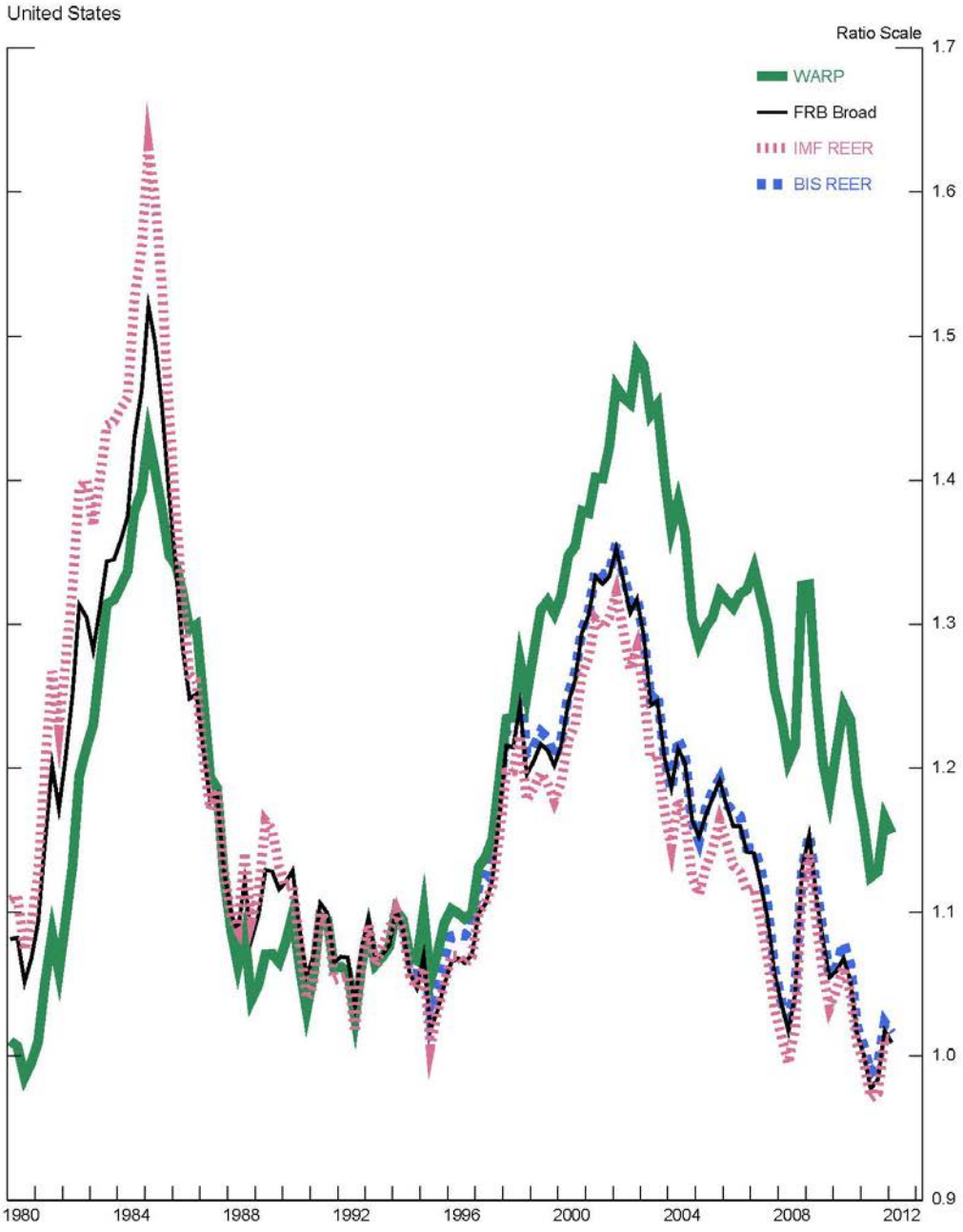


Figure 3
International Relative Prices: WARP and REERs



BIS and IMF REERs and FRB Broad Index are renormalized to equal the value of WARP in 1994:Q1 -the first date for which the BIS series is available.