Demand for International Reserves: A Quantile Regression Approach

Sula, Ozan

Western Washington University

2008

Demand for International Reserves: A Quantile Regression Approach

Ozan Sula[*]

Department of Economics, Western Washington University, Bellingham, WA 98225, USA

Abstract

I estimate the determinants of the demand for international reserves using quantile regressions. Employing a dataset of 96 developing nations over the period of 1980-1996, I find considerable differences at different points of the conditional distribution of reserves. The ordinary least squares estimates of elasticities that were found to be insignificant in previous studies become statistically significant at various quantiles of the reserve holding distribution. In particular, I find that the coefficients of interest rate differential and volatility of export receipts are significant and have the signs predicted by the traditional reserve models, but only for those nations that hold the highest amount of reserves. In contrast, the flexibility of the exchange rate does not seem to be an important factor for the nations that are located at the tails of the distribution.

JEL classification: F30

Keywords: International reserves; Quantile regression; Demand for reserves; Reserve policy

[*] Tel.: +1 360 6502530; fax: +1 360 6506315; e-mail: ozan.sula@wwu.edu

I. Introduction

What determines a nations' demand for international reserves? A majority of the empirical studies that examine the determinants of demand for reserves rely on the so-called 'buffer stock' model, developed in the 1960s and 1970s (e.g., Heller, 1960; Kenen and Yudin, 1965; Kelly, 1970; Frenkel and Jovanovic, 1981). The model posits that central banks choose an optimal level of reserves to balance the costs of the macroeconomic adjustment incurred in the absence of reserves, with the opportunity cost of holding reserves. Accordingly, the model predicts that trade openness and increased volatility of external disturbances increases the need for reserves. On the other hand, higher domestic interest rates, relative to the rest of the world, will lower the demand, as they are associated with an increase in the opportunity cost. Less flexible exchange rate regimes should also require higher levels of reserves to maintain exchange rate stability.

A common empirical approach used to test the buffer stock model is to estimate a constant demand elasticity model by including the aforementioned factors as the right hand side variables in an ordinary least squares (OLS) regression. Recent examples of this approach, however, present mixed results when applied to a large sample of developing nations. The volatility of disturbances, measured as the volatility of export receipts, and the opportunity cost, measured as the differential between the domestic and US treasury bill interest rates, are found to be insignificant or enter the regressions with the wrong signs (e.g. Edison, 2003; Aizenman and Marion, 2004; Aizenman and Lee, 2007). Apart from these results, we also see that large reserve holders do not decrease their reserve holdings when they move to a relatively more flexible exchange rate regime. This was witnessed in the advanced nations after the collapse of the Bretton Woods system, but it is also being witnessed today in the emerging markets.

One key assumption of the constant elasticity specification is the homogeneity of the demand parameters across the sample. The OLS regression estimates the mean effect of the explanatory variables on the demand for international reserves and does not take full account of the heterogeneity in the sizes of reserve holdings across countries. In other words, the coefficients of the explanatory variables, or elasticities, are assumed to be identical regardless of the level of reserves.

The distribution of reserve holdings across developing nations is, however, hardly homogenous. A small number of nations hold disproportionately larger amounts of international reserves compared to the rest of the developing world. Figure 1 plots the cumulative distribution of the reserve holdings (deflated by the US GDP deflator) in a sample of 96 developing nations in 1996. The top 20% of the reserve holders hold approximately 90% of the developing countries' reserve holdings. More dramatically, the top 5 largest reserve holders hold more than 44% of the total reserve holdings in 1996 (the leading nation is China ,with one billion dollars of reserves). It is also worth noting that the largest reserve holders are among the emerging markets.

Earlier studies that examine the demand for international reserves during the 1960's also found significant differences between the demand functions of more open and less open nations (Kelly, 1970) and developed and developing nations (Kelly, 1970; Frenkel, 1974). The factors that differentiate these nations during the 1960s are similar to the factors that differentiate various developing nations in the 1980s and 1990s. If the demand for international reserves does not have a constant slope or a constant elasticity, then a sample including a large number of developing countries will provide limited information. Moreover, large reserve holders act as outliers in the OLS regression and possibly influence the results. Excluding these nations from the sample would defeat the purpose of the analysis, as they are generally the main motivation for understanding the demand for reserves. On the other hand, running a separate regression for large reserve holders would not work either, primarily due to the severe sample selection bias.

In this study, I offer to re-estimate the buffer stock model using quantile regressions. The quantile regression method, developed by Koenker and Bassett (1978), makes it possible to estimate coefficients of the demand functions at different points of the reserve holding distribution, instead of dividing them into simple categories and running separate OLS regressions. The method is robust to outliers and differentiates their effect from the other observations. Utilizing a dataset of 96 developing nations over the period 1980-1996, I employ the quantile regression method to test and compare demand elasticities at different quantiles of the distribution of reserve holdings. While the quantile regression method has become increasing popular in other fields of economics, there are very few studies that have applied it in the area of international finance.

My results show that elasticities are significantly different for nations that are at the opposite tails of the distribution. I find that the main predictions of the buffer stock model hold better for nations that hold the highest amount of reserves. More specifically, I find that the coefficients of interest rate differential and volatility of export receipts are significant and have the signs predicted by the buffer stock model for nations that are located on the right tail of the reserve distribution. In contrast, the flexibility of the exchange rates has an insignificant effect on these nations' demand for reserves.

The paper is organized as follows: In Section II, I review the basics of the buffer stock model and briefly summarize its widely used empirical specification. In Section III, I discuss the non-constant elasticities argument. Section IV describes the quantile regression methodology and the dataset. Section V presents the empirical results, and Section VI concludes.

II. The Buffer Stock Model

The buffer stock model is derived from the government's welfare maximization problem under uncertainty. The policymaker has several policy response tools under her disposal and has to choose the optimal mixture to use, when the country is faced with a random external disturbance. The weight that the policymaker gives to the reserve policy in this mixture will determine the demand for international reserves.

Consider the policy options to a fall in demand for domestic currency. The government may choose to contract the domestic money supply and therefore eliminate domestic resident's excess demand for foreign exchange. Also known as an expenditure changing policy, this type of demand policy has the aim of keeping the exchange rate stable. However, it may cause instability in domestic income, as it may involve a sharp increase in domestic interest rates.

An alternative is an expenditure switching policy which aims to affect the composition of a country's expenditure on foreign and domestic goods. One way to do this is to let the domestic currency depreciate when the demand falls. This will change the relative prices between domestic and foreign goods, eliminate the balance of payments deficit and isolate the domestic economy from the external disturbance. The isolation of the domestic income, however, may not be possible if the domestic financial system is fragile. A sizable depreciation can cause insolvency for firms with large unhedged net foreign currency liabilities. In the extreme, these can accumulate into a domestic financial crisis and have substantial negative effects on the domestic income.

Another expenditure switching policy would be to use trade barriers, like tariffs and quotas, or to restrict the flow of capital via capital controls. While these policies, in theory, may lower the impact of external disturbances, empirical studies have found that their effectiveness on maintaining domestic income stability is questionable[1]. Furthermore, it is widely accepted that these policies have substantial welfare costs.

Lastly, the reserve policy response would be to allow the foreign exchange reserves to run down to offset the excess supply of domestic currency. Thereby, the government can maintain a stable exchange rate and isolate the domestic income and price level from the external disturbance. If the government gives sufficient weight to the reserve policy, this requires that she has also sufficient quantities of reserves. Holding reserves, however, is a costly venture. The difference between the return on liquid reserve assets and the cost of borrowing from abroad, or the return on domestic assets and investment, constitute the opportunity cost of reserves.

[1] See Edwards (1999) for a review of the effectiveness of capital controls.

The optimal amount of reserves will be determined by the availability of alternative policy options, the magnitude of costs induced by the alternative policies and the opportunity cost of holding reserves. The explanatory variables that are used in the estimations of the buffer stock model arise out of the previous discussion. The following specification estimated by Aizenman and Marion (2004) summarizes the empirical models:

$$\begin{aligned} Reserve\ Holdings_{it} = {} & \beta_1\ Opportunity\ Cost_{it} + \beta_2\ Volatility\ of\ Disturbances_{it} \\ & + \beta_3\ Volatility\ of\ Exchange\ Rate_{it} + \beta_4 Openness_{it} \\ & + \beta_5\ Scale_{it} + \alpha_i + \varepsilon_{it} \end{aligned} \tag{1}$$

where *i* denotes country, *t* denotes time, β_1 through β_5 are demand elasticities, α is a country specific constant, and ε is a random disturbance term.

The first term in (1), the opportunity cost of reserves, should enter with a negative coefficient. The volatility of disturbances should have a positive coefficient. Greater variability would increase the risk of reserve depletion and translate into a larger variance of domestic income and prices. Therefore, the central banks are expected to hold a larger stock of reserves to evade the cost of restocking frequently. Volatility of the effective exchange rate is used as a proxy for the type of the exchange rate regime. Greater exchange rate flexibility is expected to lower the demand for reserves and the variable should enter with a negative coefficient. Openness is an indicator of vulnerability to external disturbances and it is expected to have a positive coefficient. The scale variable controls for the size of international transactions and it should enter with positive coefficient. Finally, α, represents the country specific factors that are not explicitly included in the model.

III. Non-Constant Demand Elasticities

A number of possible reasons for non-constant demand elasticities, explicit and implicit, are offered by the previous research: Differences in the structure of the financial or real sector, government's preferences, specific macro conditions facing the economy, or institutional and political factors are likely to imply that there is no single demand function that characterizes all nations. All of these factors help determine the costs of the alternative policies, as well as their availability, when the country faces a random disturbance.

In equation (1), it has been assumed that the variability of domestic income and prices is the major outcome of non-reserve policies. The inclusion of the volatility of disturbances and openness variables are based on this assumption. However, it is unlikely that the costs of non-reserve policies in the domestic economy would be equivalent across nations. In addition, the perception of the severity of costs will be subjective, depending on the preferences of the policymaker. This implies that when facing the same disturbance, countries may respond differently. In other words, demand curves across nations, and even across time periods, may not have a constant slope or a constant elasticity.

Conventional OLS models throw the availability and costs of alternative policies into the error term, implying that their effect is additive and independent of the other determinants of the demand for reserves. Consider two countries; one uses a reserve policy and the other uses an expenditure switching policy. Holding everything else constant, one would expect a higher demand for reserves from the first country. In addition, facing the same volatility of disturbances, the second country's demand will be inelastic. In this hypothetical situation, the usual additive least squares regression model will only capture the difference in reserve holdings, not the difference in the elasticity of demand to the volatility of disturbances.

A few studies explicitly recognize the notion of non-constant elasticities. Grubel (1971), for example, states his concerns on estimating cross-sectional demand functions instead of demand functions for individual countries from time series. He stresses the importance of unobservable taste preferences and structural characteristics of economies in determining the demand for reserves. Kelly (1970) provides a test for the difference in the coefficients of the main independent variables of the buffer stock model by running a separate regression for a divided sample of 46 developed and less developed economies, and more open and less open economies, for the period of 1953-1965. He finds that dividing the sample into two groups produce statistically different estimates for most of the coefficients.

Frenkel (1974) specifically looks at the difference between the demand for reserves by 55 developed and less-developed countries for the period 1963-1967. He shows that the demand parameters of the two groups were significantly different. He argues that these differences can be explained by the degree of sophistication of financial structures, the ability of the monetary authorities to satisfy the increased demand for money as an asset in the process of economic growth, the willingness of the government to impose direct controls on international trade, and the degree of access to the world capital markets. All of these factors vary largely across developing nations today.

Studies that analyze the large reserve holdings during the post Bretton Woods era and the 1990's also offer implicit reasons for different demand elasticities. One such group of studies analyzes the asymmetry of the country's adjustment behavior when reserves are below or above their optimal levels. For example, Claassen (1975) shows that the maximum level of reserves that nations hold are always three times higher than the target level. Willett (1980) provides a public choice analysis of the incentives facing governments with respect to reserve policy. He argues that once reserves reached an adequate level, their weight in the government's utility function may change. Selling off excess reserves can require actions that conflict with other economic objectives, for instance, by requiring appreciation. More recently, Bar-Ilan et al. (2004) and Li et al.(2007) show that a country might wish to accumulate reserves over a long period of time if the cost of adjusting reserve levels was high in relation to the cost of holding reserves. In particular, this group of studies offer answers to the question of why large reserve holders do not lower their reserve holdings when they move to a more flexible exchange rate regime.

Another group of studies offers the precautionary demand explanation (i.e. Ben-Bassat and Gottlieb, 1992a; Lee, 2004; Aizenman and Lee, 2007). Reserves can provide protection against sudden stops of capital flows and therefore provide self-insurance for nations. Furthermore, in second-generation crisis models, reserve adequacy can influence the probabilities of crisis when countries have fundamentals in the vulnerable zone (Obstfeld 1994). Thus, countries may be willing to hold more reserves to deter sudden stops of capital flows and provide liquidity, if they happen. Aizenman (1998) also shows that precautionary demand will be especially strong if the government has high aversion to loss; a factor that is thrown into the error term in standard OLS regressions.

Large reserves can also be caused by public finance problems. A country facing a combination of costly tax collection, sovereign risk and the need to finance public expenditures, may find it optimal to hold large reserves to smooth consumption (Aizenman and Marion, 2004).

Finally, accumulating reserves can be a residual of an industrial policy, where the government is deliberately preventing the exchange rate from appreciating to promote trade competitiveness. This explanation is especially motivated by China's demand for reserves in the 1990's (Dooley et al., 2003). Aizenman and Lee (2007), however, shows that the precautionary demand for international reserves explains the emerging markets' behavior better than the mercantilist view after the Asian financial crisis.

If demand elasticities vary across nations, then equation (1) will mask the potential heterogeneity across the distribution, due to its sole focus on the conditional mean. To allow for different demand elasticities, I modify (1) in the following fashion:

$$\begin{aligned} Reserve\ Holdings_{it} = {} & \beta_0(\gamma) + \beta_1(\gamma)\, Opportunity\ Cost_{it} + \beta_2(\gamma)\, Volatility\ of\ Disturbances_{it} \\ & + \beta_3(\gamma)\, Volatility\ of\ Exchange\ Rate_{it} + \beta_4(\gamma) Openness_{it} \\ & + \beta_5(\gamma)\, Scale_{it} + \varepsilon_{it} \end{aligned} \tag{2}$$

where γ is the weight given to the reserve policy. Holding everything else constant, I will assume that higher levels of reserve holdings are associated with a higher γ. Each elasticity coefficient is a function of γ, however, in equation (2), I do not define the function, and leave it to be estimated from the data. Below, I present the methodology to estimate (2).

IV. Methodology and Data

The method that would allow me to estimate equation (2) is the quantile regression developed by Koenker and Bassett (1978). It is an extension of the classical least squares estimation of the conditional mean to a collection of models for different conditional quantile functions. Since the introduction of the technique, a growing number of studies have applied it to estimate the effect of explanatory variables on the dependent variable at different points of the distribution.[2]

The basic quantile regression model specifies the conditional quantile as a linear function of explanatory variables and is given by:

$$Y = X'\beta + \varepsilon \tag{3}$$

$$Q_\theta(Y|X = x) = x'\beta(\theta) \text{ and } 0 < \theta < 1 \tag{4}$$

where Y is the dependent variable, X is a matrix of explanatory variables, ε is the error term and $Q_\theta(Y|X = x)$ denotes the θ^{th} quantile of Y conditional on $X = x$. The distribution of the error term ε is left unspecified. As is implied by equation (4), it is only assumed that ε satisfies the quantile restriction $Q_\theta(\varepsilon|X = x) = 0$.

The θ^{th} regression quantile estimate, $\hat{\beta}(\theta)$, is the solution to the following minimization problem:

$$\underset{\beta \in \Re^K}{Min} \sum_{Y \geq X'\beta} \theta |Y - X'\beta| + \sum_{Y < X'\beta} (1-\theta)|Y - X'\beta| \tag{5}$$

If θ=0.5, the procedure leads to minimizing the sum of absolute deviations, also known as the median regression. Since the median is the 50th quantile, one can apply the same procedure for other quantiles by changing θ. For example, if θ=0.80, then the negative residuals will have

[2] See Buchinsky (1998) and Koenker and Hallock (2001) for a brief survey of empirical applications.

less weight than the positive ones and equation (5) is minimized when 20 percent of the residuals are negative and we get the 80th quantile estimate. Therefore, by increasing θ continuously from 0 to 1, we can trace the distribution of *Y,* conditional on *X,* and obtain a much more complete view of the effects of explanatory variables on the dependent variable. It is also worth mentioning that segmenting the dependent variable (unconditional distribution) and then running an OLS on the subsets is not an appropriate alternative to the quantile regression, due to severe sample selection problems (Koenker and Hallock, 2001).

Note that this method allows elasticities to vary by quantiles of the unobservables or by the quantiles of the reserve holdings. The θth quantile of reserve holdings depends on two factors: the explanatory variables *X* and the quantile of the country conditional on *X*. Therefore, after conditioning out the effects of observed factors, *X*, the method will allow for comparison of the elasticities at different quantiles of unobservables. Furthermore, if we assume that $0<\gamma<1$ in equation (2), where a higher γ is associated with larger reserve holdings, then we can also assume that $\gamma = \theta$. This implies that countries that are at the higher end of the reserve holding distribution are also the ones that yield a higher weight to the reserve policy.

The components of *X* consist of the five explanatory variables from the buffer stock model from Aizenman and Marion (2004), presented in (1). This allows use of their publicly available dataset and allows for an easier comparison of estimation results.[3] The unbalanced panel dataset consists of 96 developing countries over the 1980-1996 period.[4]

It is worth mentioning that I exclude the country specific constant in the quantile regressions. Ideally, we would like to incorporate the country fixed effects in equation (2) however; both the implementation and the interpretation of country specific constants are not straightforward in the quantile regression framework.[5]

To estimate a fixed effects model, differencing (or demeaning) the data, as one would do under an OLS framework, is not appropriate for quantile regressions. As outlined in Arias et al. (2001) the quantiles of the sum of two random variables are not equal to the sum of the quantiles of each random variable. In our context, if the data is differenced, the order of the countries matters. In particular, quantile estimates of elasticity coefficients from a differenced equation would reflect the elasticity on the quantiles of the conditional distribution of within country

---

[3] Data is available at www.res.org.uk.

[4] Due to missing data on political variables investigated, Aizenman and Marion (2004) reduce the sample to 64 countries. Since I am interested in the core buffer stock model, I exclude the political variables and use the entire dataset.

[5] Fortunately, advances are being made on this issue. See Arias et al. (2001), Koenker (2004), Lamarche (2006) and Canay (2008) for various approaches to the problem.

reserve holdings, instead of the elasticities in the quantiles of the conditional reserve holding distribution.

One might be tempted to follow the alternative approach which would entail including the individual country dummy variables in the regression. Koenker (2004), however, points out that the large number of individual fixed effects can significantly inflate the variability of the estimates of the other explanatory variables' effects. To quote Koenker (2004), "At best it might be possible to estimate an individual specific location-shift effect, and even this may strain credulity."

Apart from the implementation issues, the interpretation given to individual fixed effects is less appealing in quantile regression models, as the quantile regression already accounts for unobserved heterogeneity and heterogeneous effects. For example, the examination of the data reveals that the size of a given country's reserve holdings seldom falls outside a narrow range of quantiles. Hence, the distinction among the varying sizes of reserve holdings is lost when different intercept terms are allowed for each country.

That being said, the main dependent variable, *Y,* is the log of reserves valued at US dollars divided by the US GDP deflator. As it is common in this literature, I have also used three other measures of international reserves as dependent variables, these are: Reserves as a ratio of broad money (M2), short-term debt and GDP.

Table 1 presents the descriptive statistics for the dependent and independent variables.[6] The opportunity cost of reserves is measured by the differential between the country's own interest-rate and the interest rate on US treasuries. A higher interest rate differential is associated with a higher opportunity cost. The volatility of disturbances is measured as the standard deviation of the previous years' real export receipts. Volatility of the effective exchange rate is measured as the standard deviation of previous years' nominal effective exchange rate against the US dollar. Imports to the GDP ratio are used to measure openness to trade and the vulnerability to external disturbances. Population size and real GDP per capita are used as scale variables. All the variables enter the regression in natural log form.

V. Results

To facilitate a direct comparison, the model is estimated first by pooled and fixed effects OLS regressions. Columns 1 and 2 in Table 2 present the OLS estimates. In both regressions, the coefficients of two key variables: the volatility of export receipts and the interest rate differential are not statistically significant. With the exception of the interest rate differential in the pooled

[6] See Aizenman and Marion (2004) for a more detailed description of variable definitions and data sources.

OLS regression, the signs of the other estimated coefficients are consistent with the predictions of the buffer stock model. These results are also in line with Aizenman and Marion's findings.[7]

Next, I have estimated the model for different values of θ that allow an examination of the impact of the explanatory variables at different points of the distribution of the countries' reserve holdings. In addition, I have also run interquantile regressions, which produce estimates of the difference in coefficients at adjacent quantiles. The difference estimates can be tested for statistical significance and therefore offer a test for the constant elasticity hypothesis.

The quantile regression estimates are reported in Table 2 (columns 3-7). The model is estimated at the 5th, 25th, 50th, 75th, and 95th quantiles. The standard errors for the quantile estimates are obtained by bootstrapping with 1000 replications. Table 3 presents the difference estimates.

We see that there are some pronounced differences across different points in the distribution of reserve holdings. First, note the variables that have insignificant coefficients in the OLS regressions. The interest rate differential and the volatility of export receipts both enter the regression with statistically significant coefficients at various quantiles of the distribution. Second, glancing over Table 3, we see that some of the interquantile estimates for these two variables' coefficients are statistically significant. This proves that the elasticities are not constant across the various quantiles of the reserve distribution.

The interest rate differential enters the regression with an insignificant and positive coefficient at the 5th quantile. It becomes significant, gradually falls and turns negative towards the right end of the distribution. At the 95th quantile, the coefficient is negative and highly significant as the buffer stock model suggests, but this is not true in any of the other quantiles. Table 3 also shows that the coefficients at the 75th quantile and 95th quantile are significantly different. The interest rate elasticity of demand for reserves is not constant and rises with higher levels of reserves.

One interpretation of this result is that the opportunity cost of holding reserves rises at an increasing rate as the reserve holdings increase. However, some caveats are worth mentioning. Previous studies have consistently pointed out the possibility of the endogeneity of the interest rate differential. The direction of the bias from the endogeneity, however, is not clear. On the one hand, higher levels of reserves could lower the probability of an external crisis and the risk premium on domestic assets and lead to lower domestic interest rates (Levi-Yeyati, 2006). In this

[7] Aizenman and Marion (2004) do not report the results when the interest rate differential variable is included in their model, but they state that it is insignificant and have entered it with the wrong sign (positive) in all their regressions.

case, we would observe a negative coefficient estimate. On the other hand, higher interest rates might attract large capital inflows, which, in turn, may trigger an intervention from the central bank to prevent currency appreciation. This would cause a positive relationship between the reserves and the interest rates. The sharp contrast between the coefficients at the lower and higher quantiles might also suggest that the causes of the endogeneity changes across the quantiles.

The next determinant of the demand for reserves: the coefficient of the volatility of export receipts, is both significant and has the expected positive sign at the higher quantiles. The relatively large and significantly negative coefficient at the 5th quantile is difficult to explain, yet the coefficient is insignificant on the left side of the distribution. Furthermore, Table 3 confirms that the coefficient is statistically different across quantiles and increases in size as we move towards the right side of the distribution.[8] If, at the lower quantiles of the distribution, nations place a lower weight on reserve policy in their reaction to random disturbances, then we expect their demand for reserves to be less sensitive to the volatility of international transactions. The sharp change in significance and sizes of coefficients at the right side of the distribution confirms this hypothesis.

Another noteworthy result is the effect of the volatility of the effective exchange rate. It enters with insignificant coefficients at both tails of the distribution. It does, however, exhibit statistically significant negative signs in the middle section. In Table 3, we see that the coefficients at the 25th through the 75th quantiles are not statistically different from each other. Coefficients at the highest and lowest tail, however, as shown in Table 2, are not statistically different from zero. If nations at the higher end of the distribution mainly rely on reserve policy, due to other reasons, then we would not expect them to be sensitive to the changes in the exchange rate. In fact, lowering the reserve holdings after moving to a more flexible exchange rate regime may require substantial adjustment costs. The insignificant coefficient at the 95th quantile is consistent with the persistence of large reserve holdings, when nations switch to relatively more flexible exchange rate regimes.

The imports to GDP variable enters with statistically significant positive coefficients in every quantile. Furthermore, interquantile estimates in Table 3 show that coefficients at various quantiles are not statistically different from each other (with the exception of the coefficients at the 25th and 50th quantiles). Likewise, the significance of the scale variables; population size and real GDP per capita, do not change. The variation in the two scale coefficients at different quantiles seems to offset each other.

[8] 75th-95th quantile estimate is marginally significant (p-value of 0.12).

I regress several other measures of international reserves on the buffer stock variables to see if the results are robust. Figure 2 presents a graphical summary of the quantile regression results when four different measures of reserve holdings are used. Each figure plots the quantile regression point estimates for θ in increments of 0.05, ranging from 0.05 to 0.95, as the solid curve. This solid curve illustrates the change in coefficient estimates as we move from one quantile to another, holding other independent variables constant. The shaded area around the solid line shows the 90% confidence interval constructed by the 1000 bootstrap replications. The solid straight line in each figure represents the fixed effects OLS estimate and the dashed lines above and below that line show the borders of the 90% confidence interval.

Column (1) in Figure 2 provides a more complete picture of the elasticities presented in Table 2. Columns (2), (3) and (4) present coefficient estimates when reserve holdings are defined as a ratio of broad money (M2), short-term debt and GDP, respectively. While the results from earlier analysis show some sensitivity to the use of reserves over the M2 ratio, most of the qualitative results continue to hold. The estimates for the coefficients of volatility of export receipts are increasing towards the higher quantiles of the reserve holding distribution. In contrast, we see a decreasing pattern for the interest rate differential. The u-shaped pattern for the volatility of the exchange rate coefficients also continues to be observed in all four regressions. The estimates for the coefficients of the scale variables, and imports to GDP measure, do not exhibit a clear pattern.

VI. Conclusions

I used quantile regressions to re-estimate the buffer stock model at different points of the reserve holdings' conditional distribution. I found that the parameters of the demand function vary across nations with different levels of reserve holdings. The results also show that some of the elasticity estimates that are found to be insignificant in the OLS regression, become statistically significant at the various quantiles of the reserve holding distribution. More specifically, I found that the coefficients of the interest rate differential and volatility of export receipts are significant and have the signs predicted by the buffer stock model for nations that hold the highest amount of reserves. In contrast, the flexibility of the exchange rates is not an important determinant of demand for those nations located at the tails of the distribution.

These findings have several implications for future empirical research on the demand for international reserves. First, the results imply that the behavior of emerging markets is significantly different than other developing nations. This finding is due to the stylized fact that the largest reserve holders in the sample, nations that are at the right hand of the distribution, are emerging markets. Furthermore, the results show that there are significant differences in elasticities, even among the emerging markets. Studies that estimate the buffer stock model using OLS should pay special attention to the emerging markets, possibly estimating them separately from other developing nations.

Second, the results reveal the importance of the unobservable factors on the demand for reserves. In particular, variables that would capture the weight given by the governments to the reserve policy would substantially improve the explanatory power of the model. These factors may help explain the difference in demand behavior between emerging markets and other developing nations.

Third, the sharp contrast in the coefficients of some of the estimates across the quantiles may be due to endogeneity, rather than heterogeneity. This possibility is especially high for the interest rate differential. One way to mitigate the endogeneity problem is to include country specific constants in the quantile regression. I have summarized the limitations of fixed effects quantile regressions, yet other studies on panel data quantile regressions may help address this issue in the future.

The quantile regression can provide significant improvements in our understanding of the demand for international reserves. Although my work has established the potential value of this method in this line of research, it does not explicitly explain the reasons of fast reserve accumulation in emerging markets or predict reserve holdings after 1996. I leave this significant topic for future analysis.

Acknowledgements

Funding for this research was provided through Western Washington University's Bureau for Faculty research. I thank Ozkan Eren, Salem Nechi, Serkan Ozbeklik, and Thomas D. Willett for their comments and suggestions. I take full responsibility for any errors.

References

Aizenman J. Buffer stocks and precautionary savings with loss aversion. Journal of International Money and Finance 1998; 17; 931-947.

Aizenman J, Lee J. International reserves: precautionary vs. mercantilist views, theory and evidence. Open Economies Review 2007; 18; 191-214.

Aizenman J, Marion N. The high demand for international reserves in the Far East: What's going on? Journal of the Japanese and International Economies 2003; 17; 370-400.

Aizenman J, Marion N. International reserve holdings with sovereign risk and costly tax collection. The Economic Journal 2004; 114; 569-591.

Arias O, Hallock K, Sosa-Escudero W. Individual heterogeneity in the returns to schooling: instrumental variables quantile regression using twins data. Empirical Economics 2001; 26; 7-40.

Bar-Ilan A, Marion N, Perry D. Drift control of international reserves. Journal of Economic Dynamics and Control 2007; 31; 3110-3137.

Ben-Bassat A, Gottlieb D. Optimal international reserves and sovereign risk. Journal of International Economics 1992a; 33; 345-362.

Ben-Bassat A, Gottlieb D. On the effect of opportunity cost on international reserves holdings. Review of Economics and Statistics 1992b; 74; 329-338.

Buchinsky M. Recent advances in quantile regression models: a practical guide for empirical research. Journal of Human Resources 1998; 33; 88-126.

Canay I. A note on quantile regression for panel data models, manuscript University of Wisconsin – Madison; 2008.

Claassen E-M. 1975. Demand for International Reserves and the Optimum Mix and Speed of Adjustment Policies. American Economic Review 1975; 65; 446-453.

Dooley M, Folkerts-Landau D, Garber P. An essay on the revived Bretton Woods system. NBER Working Paper # 9971; 2003.

Edison H. Are foreign exchange reserves in Asia too high? In: World Economic Outlook, International Monetary Fund, Washington DC; 2003.

Edwards S. How effective are capital controls? Journal of Economic Perspectives 1999; 13; 65-84.

Flood R, Marion N. Holding international reserves in an era of high capital mobility, in: Collins, S.M., Rodrik, D., (Eds.), Brookings Trade Forum, Brookings Institute Press, Washington DC; 2002. p.1-47.

Frenkel J. The demand for international reserves by developed and less-developed countries. Economica 1974; 41; 14-24.

Frenkel J, Jovanovic B. Optimal international reserves: a stochastic framework. The Economic Journal 1981; 91; 507-514.

Grubel H. The demand for international reserves: a critical review of the literature. Journal of Economic Literature 1971; 9; 1148-1166.

Heller R. Optimal international reserves. The Economic Journal 1966; 76; 296-311.

Kelly M. Demand for international reserves. American Economic Review 1970; 59; 655-667.

Kenen P, Yudin E. The demand for international reserves. Review of Economics and Statistics 1965; 47; 242-250.

Koenker R. Quantile regression for longitudinal data. Journal of Multivariate Analysis 2004; 91; 74-89.

Koenker R, Bassett G. Regression quantiles. Econometrica 1978; 46; 33–50.

Koenker R, Hallock K. Quantile Regression. Journal of Economic Perspectives 2001; 15; 143-156.

Lamarche C. Robust penalized quantile regression estimation for panel data, manuscript, University of Oklahoma; 2006.

Lee J. Insurance value of international reserves. IMF working paper #04/175; 2004.

Levi Yeyati E. The cost of reserves. Universidad Torcuato Di Tella Business School Working Papers, 2006-10; 2006.

Li, J., Sula, O., Willett, T.D. A new framework for analyzing adequate and excessive reserve levels under high capital mobility. In: Cheung, Y., Wong, K. (Eds), China and Asia, Routledge Studies in the Modern World Economy 76, Routledge, 2008 p. 230-245.

Obstfeld M. The Logic of Currency Crises. Cahiers Economiques et Monetaires 1994; 43; 311-325.

Willett T. International Liquidity Issues. American Enterprise Institute, Washington DC; 1980.

Figure 1: Cumulative Distribution of Real Reserve Holdings, 1996.

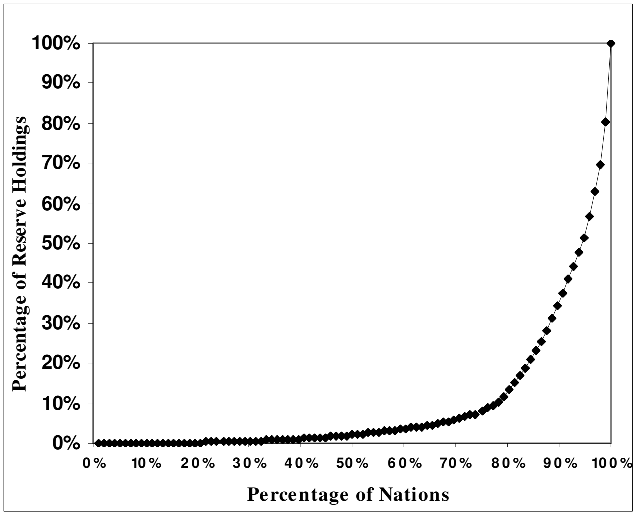
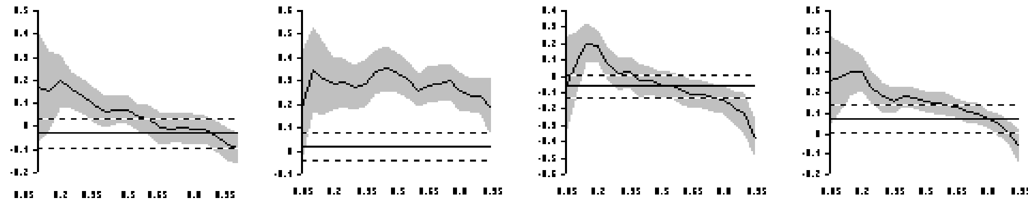


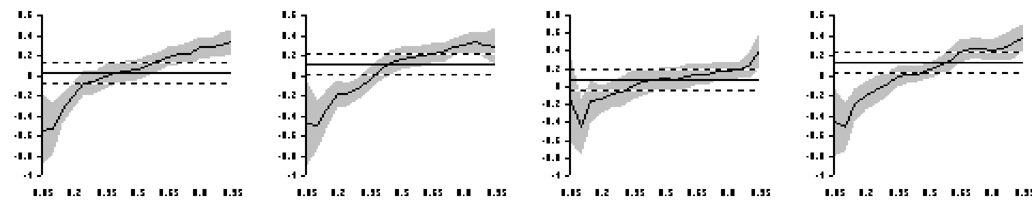
Figure 2: OLS and quantile-regression results using the logarithm of four alternative definitions of reserve holdings as the dependent variable.

Dependent Variables:	Reserves / US Deflator	Reserves / M2	Reserves/ST Debt	Reserves / GDP
Explanatory Variables:	(1)	(2)	(3)	(4)

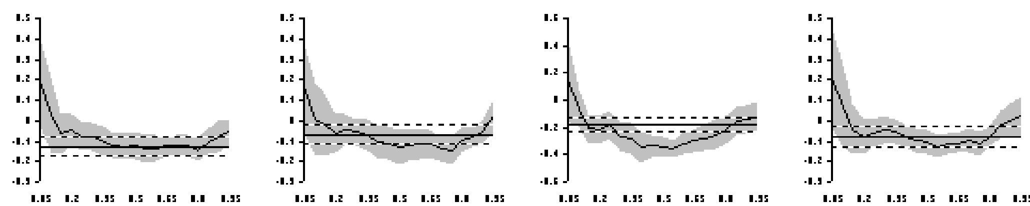
Interest rate differential



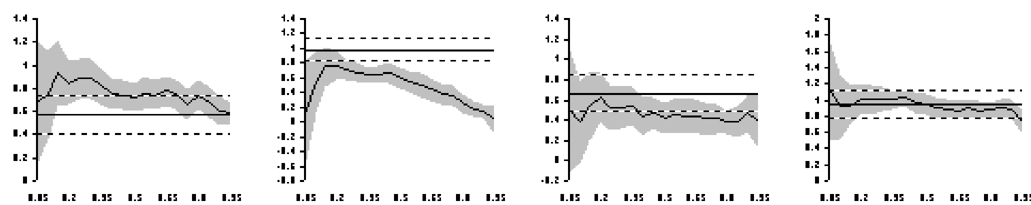
Volatility of export receipts



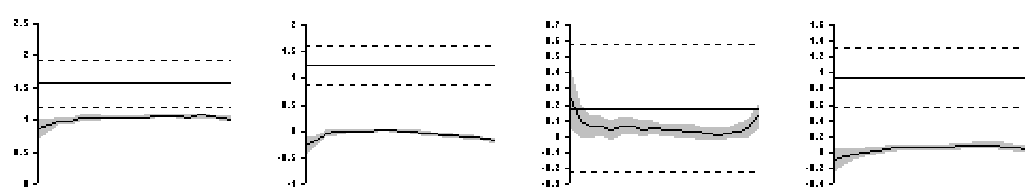
Volatility of effective exchange rate



Imports to GDP



Population



Real GDP per capita

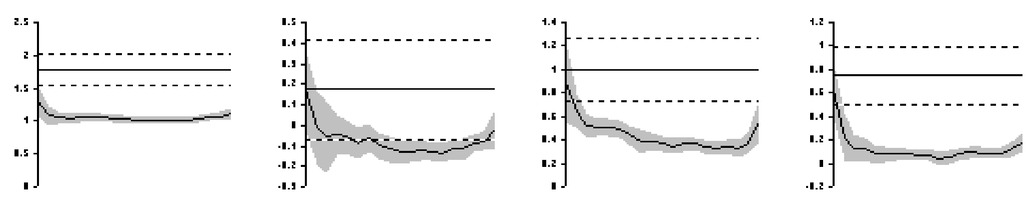


Table 1: Descriptive Statistics

	Mean	Median	St. dev.
Real Reserve Holdings (mil $)	25.0	2.8	66.0
Reserves to M2 ratio (%)	29.5	0.2	42.6
Reserves to Short-term Debt (%)	26.8	0.1	59.2
Reserves over GDP (%)	9.7	0.07	12.3
Interest rate differential	16.13	1.35	341.39
Volatility of export receipts	0.19	0.17	0.10
Volatility of effective exchange rate	0.037	0.01	0.112
Imports to GDP (%)	40.6	33.9	23.8
Population size (mil)	42.9	6.3	153
Real GDP per capita ($)	1778.0	1127.7	1776.9

Table 2: OLS and quantile-regression results using the logarithm of real international reserve holdings as the dependent variable.

Sample Size: 1349	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	OLS Pooled	OLS Fixed Effects	Quantile				
			5th	25th	50th	75th	95th
Interest rate differential	0.062	-0.03	0.172	0.134***	0.038***	-0.012	-0.096***
	(0.069)	(0.038)	(0.148)	(0.046)	(0.034)	(0.039)	(0.044)
Volatility of export receipts	0.035	0.025	-0.542**	-0.078	0.057	0.223***	0.334***
	(0.115)	(0.064)	(0.215)	(0.072)	(0.062)	(0.069)	(0.069)
Volatility of effective exchange rate	-0.057	-0.128***	0.191	-0.075*	-0.124***	-0.122***	-0.057
	(0.072)	(0.028)	(0.131)	(0.044)	(0.042)	(0.032)	(0.038)
Imports to GDP	0.689***	0.574***	0.673**	0.887***	0.724***	0.663***	0.584***
	(0.151)	(0.100)	(0.322)	(0.107)	(0.076)	(0.079)	(0.060)
Population size	1.016***	1.568***	0.861***	1.026***	1.034***	1.0445***	1.013***
	(0.047)	(0.226)	(0.096)	(0.030)	(0.020)	(0.021)	(0.024)
Real GDP per capita	1.059***	1.785***	1.304***	1.067***	1.022***	1.021***	1.121***
	(0.083)	(0.148)	(0.131)	(0.043)	(0.032)	(0.031)	(0.044)

All variables enter the regressions in logarithms. Standard errors are in parenthesis below each parameter estimate. Quantile regression standard errors are based on bootstrap with 1000 replications. * indicate statistical significance at 10%; ** indicate significance at 5% and *** indicate significance at 1%. All regressions include a constant term.

Table 3: Inter-quantile regression results using the logarithm of real international reserve holdings as the dependent variable.

Sample Size: 1349	(1)	(2)	(3)	(4)
	Quantile			
	5th - 25th	25th - 50th	50th - 75th	75th - 95th
Interest rate differential	-0.038	-0.096**	-0.05	-0.084**
	(0.131)	(0.038)	(0.035)	(0.044)
Volatility of export receipts	0.464**	0.135**	0.166***	0.11
	(0.210)	(0.069)	(0.061)	(0.070)
Volatility of effective exchange rate	-0.266**	-0.049	0.002	0.065*
	(0.124)	(0.040)	(0.036)	(0.041)
Imports to GDP	0.213	-0.162*	-0.061	-0.078
	(0.318)	(0.091)	(0.070)	(0.079)
Population size	0.164*	0.008	0.011	-0.032
	(0.091)	(0.025)	(0.020)	(0.027)
Real GDP per capita	-0.237*	-0.045	-0.0005	0.099**
	(0.128)	(0.037)	(0.029)	(0.041)

Standard errors are in parenthesis below each parameter estimate. Standard errors are based on bootstrap with 1000 replications. * indicate statistical significance at 10%; ** indicate significance at 5% and *** indicate significance at 1%.