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NÚMERO 127

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REAL EXCHANGE RATE UNCERTAINTY AND ECONOMIC PERFORMANCE IN MEXICO, 1971-1996

Introduction

The empirical literature on the real effects of exchange rate uncertainty has generally concentrated on the relationship between uncertainty and trade, using a variety of uncertainty and exchange rate measures. However, there is a growing realization that real exchange rate uncertainty may, especially in developing countries, have direct effects on growth, independent of any indirect effects via its influence on trade.

In this paper we consider two empirical questions. First, is there a real exchange rate (RER) uncertainty effect on economic growth independent of its potential effects on trade? Second, is there a relationship between the level of the real exchange rate and its conditional variance?

Using a multivariate GARCH-M model, we estimate a simultaneous model of the RER-economic growth process in Mexico from 1971 through 1996. We find that the conditional variance of the RER has a negative and significant influence on Mexican industrial production growth, controlling for industrial production growth in the USA, the level of the RER, and Mexican export growth. We also find that there is a positive and significant relationship between the level and conditional variance of the RER. That is to say, as the peso experiences real appreciation, its conditional variance rises. Taken together, these results imply that real exchange rate uncertainty is a problem for economic growth, and one way to combat the problem is to avoid RER appreciations unrelated to improved fundamentals.

Our results are novel in that they provide the first time series evidence of a link between RER uncertainty and economic growth, and the first evidence that RER appreciation increases RER uncertainty.

In what follows below, section I reviews the empirical literature on the real effects of exchange rate uncertainty, paying specific attention to the methods used to estimate uncertainty. Section II makes the case for studying growth rather than trade, LCD's rather than industrial democracies, and for using real, rather than nominal exchange rates when looking for the real effects of exchange rate uncertainty.

Section III presents a simple model showing why it may be reasonable to expect a positive relationship between the level and conditional variance of the real exchange rate. Section IV makes the case for using MGARCH-M modelling to test for the real effects of uncertainty. Section V presents the model to be estimated, section VI contains our empirical results, and section VII ends the paper with a discussion of our work and suggestions for future research.

I. Literature Review

Our purpose here is not to exhaustively review either the theoretical or empirical literatures. We merely wish to summarize in general terms what has gone on in the literature and demonstrate that an important class of evidence, namely time series evidence on the effect of ER uncertainty on economic growth, independent of any trade related effects, does not as yet exist.

A. ER uncertainty and Trade

There are a number of theoretical models that predict a non-zero relation between ER uncertainty and trade volumes or prices. In some cases the effect may be either positive or negative depending on the degree of risk aversion in the domestic economy.[1] Panel A of Table 1 summarizes 13 recent empirical studies of this relationship. 4 of these use cross sectional regressions and measure uncertainty by the sample variance or standard deviation of the exchange rate. Another 3 use time series regressions and measure uncertainty by a rolling sample standard deviation of the exchange rate. The first method constrains uncertainty to be constant over time in each country, while the second assumes that uncertainty is significantly variable in each country, though each run the risk of mistaking volatility for uncertainty. Six of these seven studies fail to demonstrate a robust relationship between ER uncertainty and trade. Three other studies use ARCH or GARCH methods. Two of them generate an uncertainty measure with an ARCH model and then use that measure in a subsequent regression model. The other estimates a simultaneous MGARC H-M model of the exchange rate and trade. These three studies each find a generally significant relationship.

B. ER uncertainty and Growth

To date, there are 2 empirical studies of the effects of exchange rate uncertainty on economic growth. These papers are summarized in part B of Table 1. Both are cross sectional studies that use sample variances or standard deviations of the real exchange rate, thus constraining uncertainty in each country to be constant over time. Both of them find a negative and significant relation between RER uncertainty and growth. However, neither include a trade variable to control for the possibility that the effect of RER uncertainty on growth is coming through trade.

1 Côté (1994) provides an excellent survey on the relationship between exchange rate volatility and trade from both theoretical and empirical points of view.

C. *What is Missing?*

In the current literature, there are no time series tests for an RER uncertainty – economic growth linkage. Our goal is to provide such a test using an MGARCH-M methodology similar to that of Kroner and Lastrapes. We also derive and test the proposition that higher RERs generate more uncertainty. In the following section, we explain why we have chosen Mexico to test these hypotheses.

II. Exchange Rate Volatility and Economic Performance in Mexico

Mendoza (1997) provides the theoretical justification for a link between real exchange rate uncertainty and economic growth. He considers a stochastic, one sector, endogenous growth model with a representative, risk adverse, agent. He assumes that the agent cannot insure against fluctuations in the return to savings denominated in the price of imported goods (which is what is consumed in the model). He then shows that increased terms of trade uncertainty can either raise or lower average growth rates depending on the degree of risk aversion extant. With a low (high) level of risk aversion, increased uncertainty will lower (raise) growth. The welfare effects of increased uncertainty though, are unambiguously negative.

In the empirical work reported below, we use the real exchange rate instead of a direct measure of terms of trade and test the time series effects of real exchange rate fluctuations and uncertainty on economic growth in models that control for the effect of trade on economic growth

A. Choice of Mexico

We believe that Mexico is an excellent laboratory to study this question for at least three reasons. First, there were no forward markets in the Peso before March of 1995, so agents would have difficulty insuring against exchange rate risk.[2] Second, many Mexican businesses import a large amount of their inputs, heightening the sensitivity of their profits to exchange rate fluctuations. Third, many large Mexican firms are closely held, meaning that owners are not well diversified and can be expected to be risk averse with respect to their own firms' profits.3 Thus the match

2 In the finance literature, Froot, Scharfstein and Stein (1993) and Stulz (1990) argue that without hedging, firms are more likely to pursue suboptimal investment projects thus affecting economic growth.

3 . For example, La Porta, Lopez-de-Silanes, Shleifer, and Vishny (1996) show that in their sample of 49 countries, the average percentage of common stock held by the 3 largest private shareholders in the 10 largest firms is 40%. In contrast the figure for Mexico is 64% which is the highest concentration in the sample (See their Table 10 column 2 for details).

between the assumptions of the Mendoza model and conditions in Mexico is much closer than it would be using data for the US or other more advanced economies.

B. Choice of Exchange Rate

Mendoza (1997) clearly points to changes in the real terms of trade and its volatility, as the factors relevant to individual's choices, thus we choose to use a real exchange rate. While the Mexican economy is now quite integrated with the US economy, this was not always the case throughout our sample, so we use a trade weighted effective real exchange rate.4

For the above reasons we investigate the relationship between real exchange rates, RER uncertainty and economic performance in Mexico, a LDC with many of the specific features discussed above. We use a multivariate GARCH-M model to estimate the conditional means, variances, and covariance of the real exchange rate and output along with the effects of uncertainty on the conditional means. However, before proceeding to test for growth effects of the RER, we must develop our second hypothesis about the linkage between the level of the RER and its conditional variance, or uncertainty.

III. Does a higher RER create more uncertainty?

It is plausible that high RER's are less predictable and therefore create more uncertainty. Here we give a simple example of how this might be the case. The argument is adapted from Ball's (1992) model of how higher inflation creates more inflation uncertainty5.

We assume that a prolonged RER appreciation hurts the export sector, creating political pressure to adjust the nominal exchange rate. However, the public does not know whether the policymaker is *tough* and will never devalue or is *soft* and will devalue in response to political pressure. When the RER is sufficiently low, neither type of policymaker will act to change it, but when the RER is sufficiently

4 When calculating an RER, the choice of price index becomes an issue. Traditionally, two representations of the RER have been used in both theoretical and empirical work. The first involves the relative price of tradable goods in terms of non-tradable ones. The second definition is based on purchasing power parity (PPP) where the nominal exchange rate is deflated by a domestic price index and inflated by an external price index. We use this latter definition in this work and utilize CPI as the appropriate index.

5 For empirical evidence on the relevance of Ball's model, see Grier and Perry (1998) who find strong link between higher inflation and greater uncertainty in each of the G-7 countries and Grier and Grier (1998) who find the same result in México.

high, a *soft* policymaker will devalue. Thus with a given policymaker of unknown type, the probability of a devaluation rises with the level of the RER (even if the policymaker is actually *tough*).

Even once a policymaker's type is known, there can still be greater uncertainty with a high RER if we assume that policymakers change over time. With a low RER, the type of the new policymaker is not currently important because neither type will intervene. However, with a high RER, the type of the new policymaker is important because one will maintain the *status quo* and the other will intervene. Thus the possibility of a future devaluation rises, ceteris paribus, as the level of the RER rises, meaning that uncertainty about the future RER is a positive function of the current level of the RER.

In section VI below we test this hypothesis by including the lagged level of the RER in the equation for the conditional variance of the RER, testing whether higher RERs in the past are associated with less predictable RERs in the present.

IV. Benefits of MGARCH-M Modeling

Testing any theory about the real effects of uncertainty requires the construction of a specific, numerical measure for uncertainty. The two methods typically used in the literature are the cross-sectional dispersion of individual forecasts from surveys or a moving standard deviation of the variable under consideration. Neither of these techniques obviously capture the economically relevant uncertainty, which is the variance of the stochastic, or unpredictable, component of a variable.

As is well known, there can be a very large difference between variability and uncertainty, depending on whether the variability is predictable in the model under consideration. Predictable fluctuations in a variable will show up in standard deviation or rolling standard deviation measures although they create no true economic uncertainty. This method of generating an uncertainty measure is used in 9 of the 15 papers surveyed above.

In contrast to the above measures, GARCH techniques specifically estimate a model of the variance of unpredictable innovations in a variable. Further, because there is an underlying parametric model, GARCH techniques are useful for at least four other reasons. First, GARCH estimation gives an explicit test of whether the movement in the conditional variance of a variable over time is statistically significant. That is, we can construct a test of the null hypothesis that uncertainty is constant over the sample period. At a minimum, one should be able to reject this null hypothesis before doing a time series test of the effect of uncertainty on macroeconomic performance. While survey or variability, or spot - forward spread based measures of uncertainty do fluctuate over time, papers using these measures typically do not present any tests for whether those fluctuations are statistically significant.

Second, MGARCH allows simultaneous estimation of the conditional variance equations and effect of uncertainty in the mean equations for the variables under consideration. Pagan (1984) shows that, when working with generated regressors, simultaneous estimation is more efficient that a two-step process.6

Third, as we show in our empirical work below, both the real exchange rate and output growth exhibit significant conditional heteroskedasticity. This means that OLS estimates of these equations are inefficient. Engle (1982) shows that the gain in efficiency from using ARCH instead of OLS when there is significant conditional heteroskedasticity can be very large.[7]

Fourth, as emphasized by Kroner and Lastrapes (1993), a simultaneous GARCH model imposes consistency and internal rationality upon market participants. We have a statistical model of the joint stochastic process for real exchange rates and output, and agents confidence intervals around expected values of the variables (i.e. their uncertainty) is derived directly from the given model. With other methods of measuring uncertainty, the implicit process driving the uncertainty can be completely different from the process implied by the model in which the investigator is going to use the uncertainty measure.

V. Statistical Model

In order to properly estimate any relationship between real exchange rate uncertainty and industrial production, we must determine the order of integration of the series, choose models for the conditional mean of each series, and then construct a simultaneous MGARCH-M system capable of testing our hypotheses. In this section we consider each of these necessary steps. The data used here are the Mexican multilateral real exchange rate with a base year of 1990 obtained from J. P. Morgan, industrial production indices for Mexico and the US taken from the IMF and Citibase respectively, and real exports for Mexico, also from the IMF.[8]

A. Order of integration

Consider first the order of integration of our four series. The case for Mexican industrial production is straightforward. Augmented Dickey Fuller (ADF) tests with

6 Feenstra & Kendall (1991) and Arize (1993) use GARCH methods to generate their uncertainty measure, but then use the measure as a generated regressor in a subseqeunt model.

7. Grier and Perry's (1993) provide an empirical example of the difference in results that can occur when existing conditional heteroskedasticity is modeled.

8. Appendix 1 contains summary statistics for the variables. US industrial production was obtained seasonally adjusted, and the Mexican series were seasonally adjusted using a procedure automated in the EVIEWS software package.

a linear trend and anywhere from 1 to 12 lagged differences never reject the null hypothesis of a unit root in the level of industrial production. However, the unit root hypothesis can always be rejected with ADF tests with from 1 to 12 lagged differences for the growth rate. Mexican Industrial production is not trend stationary, but rather is clearly integrated of order one [I(1)]. Similar results are obtained for US industrial production, and real Mexican exports.[9]

However, the case of the Mexican real exchange rate is different. While several studies have shown that nominal exchange rates are random walks, our series for the Mexican real exchange rate is trend stationary. ADF tests using a linear trend and from 1 to 12 lagged differences reject the null of non-stationarity 10 of 12 times. The non-rejections come with lags of 3 or 4 difference terms. An inspection of the correlogram for the real exchange rate reveals that the most logical selections of a lag length would be 5 or 9 lags. Therefore we proceed with a model where the conditional variance of the exchange rate potentially affects the growth rate of industrial production, and where a linear trend term belongs in the exchange rate equation.

B. Granger causality between real exchange rates and output growth

We need to capture any relevant relationship between the mean of the real exchange rate and industrial production growth, to avoid the possibility of generating a spurious relationship between the conditional variance of one series and the mean of another in our MGARCH-M model. A series of pairwise Granger causality tests reveals that the real exchange rate statistically causes industrial production growth, but that economic growth does not statistically cause the real exchange rate. Granger causality tests reveal no link between US and Mexican industrial production growth, but there is a contemporaneous correlation that we interpret as coming from US growth rates to Mexican growth. We thus incorporate lagged RER and contemporaneous US industrial production growth into our equation for the conditional mean of Mexican industrial production growth.[10]

Given that there is some evidence that RER uncertainty affects trade and also evidence that trade affects growth, it is important to control for trade when testing whether RER uncertainty directly influences growth. As discussed above, the existing cross-sectional studies that demonstrate an uncertainty - growth linkage did not include any trade variables in the growth equation. Thus they are unable to

9. See appendix 2 for details on these stationarity tests. US industrial production fails the ADF test 11 of 12 times, Mexican IP and real exports fail 12 of 12 times. All three series pass ADF tests in their logged differences 12 of 12 times.

10. In a series of Granger tests using from 1 to 6 lags, the RXR always causes Mexican IP growth at the 0.01 level while Mexican IP growth never causes the RXR. In the case of US and Mexican IP growth, neither causes the other at the .05 level in tests using from 1 to 6 lags.

distinguish between the hypothesis that uncertainty affects trade which affects growth, and the hypothesis that uncertainty directly affects growth.

Here we include real export growth in the Mexican IP growth equation to capture the effects of trade on growth. The inclusion of this variable means that it will only be the part of RER uncertainty uncorrelated with real export growth that can influence industrial production growth. Since we are using the export variable as a control, we experimented with lag lengths to find the best fitting version of the variable. Consequently we use a six-month moving average of real export growth in our MGARCH-M model.

The statistical model for the conditional mean of the real exchange rate will be an ARMA plus linear trend. Preliminary OLS estimates of such models produce single equation R^2's of over 0.90. The model for industrial production is an ARIMA plus the lagged exchange rate, lagged export growth, and growth in US industrial production. Preliminary OLS estimates of such models produce single equation R^2's of around 0.35. We will choose the exact ARMA terms used in the MGARCH-M system to maximize the likelihood function and to guarantee white noise residuals, squared residuals and cross residuals.

C. *MGARCH-M systems for testing our hypotheses*

The system of equations to be estimated has the following general form:[11]

$$RXR_t = \alpha_0 + \Sigma\, \alpha_i\, RXR_{t-i} + \beta_0 Trend_t + \Sigma\, \beta_i\, \varepsilon_{t-i} + \delta_1 \sigma^2_{\varepsilon t} + \delta_2 \sigma^2_{vt} + \varepsilon_t \qquad (1)$$

$$\sigma^2_{\varepsilon t} = \gamma_0 + \gamma_1\, \varepsilon^2_{t-1} + \gamma_2\, \sigma^2_{\varepsilon t-1} \qquad (2)$$

$$Y_t = \theta_0 + \Sigma\theta_i Y_{t-i} + \Sigma\phi_i\, v_{t-i} + \Phi_1 YUSA_t + \Phi_2\, RXR_{t-1} + \Phi 3\ \ Exports_{t-1} + \delta_3 \sigma^2_{\varepsilon t} + \delta_4 \sigma^2_{vt} + v_t \qquad (3)$$

$$\sigma^2_{vt} = \lambda_0 + \lambda_1\, v^2_{t-1} + \lambda_2\, \sigma^2_{vt-1} \qquad (4)$$

$$COV_t = \rho(\sigma_{\varepsilon t}\sigma_{vt}) \qquad (5)$$

Equation 1 is the real exchange rate equation, with ARMA terms, a linear trend and the conditional variances of the real exchange rate and industrial production growth. Equation 2 is a GARCH(1,1) model of the conditional variance of the real exchange rate. Equation 3 is the industrial production growth equation with ARMA terms, the lagged real exchange rate, US industrial production growth,

11 The model is called MGARCH-M because we are estimating the stochastic process of more than one series (M), using a GARCH model as the basis for the conditional variances, and including these conditional variances as explanatory variables in the equations for the means of our series (-M).

real export growth, and the conditional variances of the real exchange rate and industrial production growth.

To test the hypothesis that exchange rate uncertainty has real effects on economic growth, the key coefficient is δ_3, which gives the effect of the conditional variance of the real exchange rate on the growth rate of industrial production controlling for trade effects. Our argument is that δ_3 will be negative and significant.

Equation 4 is a GARCH(1,1) model of the conditional variance of industrial production growth, and equation 5 is a simple, constant correlation, model of the covariance of the two error terms.

As discussed above, we are also interested in the effect of the level of the real exchange rate on the degree of exchange rate uncertainty. To test the hypothesis that higher real exchange rates are more uncertain, we replace equation 2 above with equation 2* below:

$$\sigma^2_{\varepsilon t} = \gamma_0 + \gamma_1 \varepsilon^2_{t-1} + \gamma_2 \sigma^2_{\varepsilon t-1} + \gamma_3 RXR_{t-1}$$
(2*)

Here the conditional variance of the real exchange rate is GARCH(1,1) with a lag of the real exchange rate added. The key coefficient for our hypothesis is γ_3. If γ_3 is positive and significant, we have support for our modified Ball model.

VI. Results

Table 2 presents maximum likelihood estimates of the MGARCH-M model given in equations 1-5 above.12 To determine the exact ARMA terms included in the mean equations we initially considered up to 12 autoregressive terms, retaining the ones with significant coefficients. In the industrial production growth equation, this was sufficient to produce white noise residuals and squared residuals. The real exchange rate equation requires an additional step of considering up to 12 moving average terms to produce both residuals and squared residuals without any autocorrelation. The conditional variance of output growth, while significantly time varying, is not very persistent and is best modeled as an ARCH(1) instead of a GARCH(1,1) process.

Before examining the coefficients in detail, it is important to note that the chosen covariance structure is both statistically significant and sufficient to eliminate any patterns in the squared residuals. The 2 conditional mean equations (1 & 3) estimated as a system with no uncertainty terms and constant conditional variances produces a maximized value of the log likelihood function of -2498 and

12. We estimate the model by assuming that the two error terms are multivariate normal, choosing a set of starting values for all the coefficients of the model and then using the well-known BHHH algorithm to arrive at a coefficient matrix that maximizes the value of the likelihood function.

imposes 8 restrictions on the model in Table 2. The full model shown in Table 1 produces a log likelihood of -2370. We can construct a significance test for the GARCH and GARCH-M variables by using the fact that -2(change in log likelihood) is distributed as a χ^2 with degrees of freedom equal to the number of restrictions (in this case 8). Our estimated χ^2 statistic is 264 and is significant at the 0.01 level. The Box
Lung Q statistics presented at the bottom of the Table show that there are no exploitable patterns remaining in the level, squares, or cross-products of the residuals.

Equation 1 of Table 2 models the real exchange rate as a function of the first, second, fifth, sixth and tenth lags of the real exchange rate along with the first, third, sixth and tenth moving average terms, a linear trend, and the conditional variances of the RXR and output growth. Equation 3 models output growth using the first, second, seventh and eighth lags of output growth along with industrial production growth in the US and the lagged real exchange rate, which are both positive and significant and the conditional variances of the RXR and output growth. This equation contains the estimated coefficient for the effect of real exchange rate uncertainty on industrial production growth (δ_3 as discussed above). The coefficient is -1.36 with a t-statistic of 3.92. That is to say, ***increased real exchange rate uncertainty significantly depresses industrial production growth in Mexico*** during our (1971 - 1996) 26-year sample.

Equation 2 shows the ARMA(1,1) model for the conditional variance of the RER, Equation 4 shows the MA(1) model used for the conditional variance of industrial production growth and equation 5 shows that there is a negative and marginally significant covariance between the innovations of the two series. The estimated conditional variances for the RER and IP growth are displayed in Figures 1 and 2 respectively.

The MGARCH-M system contains strong evidence that real exchange rate uncertainty is detrimental to the economic performance of the Mexican economy. This result is new and important in several senses. First, it is found in a developing country rather than the widely studied G-7 countries. Second, it is found for overall economic activity rather than simply for trade, which is the variable generally studied. Third, it is found in a simultaneous multi-equation system instead of with the two step estimation process usually employed in the literature. Fourth, it is found using real exchange rates, which implies that a government policy of a pegged nominal exchange rate may be insufficient to avoid economically costly exchange rate uncertainty.

To analyze the effect of changes in the real exchange rate on output growth in Table 2 it is necessary to distinguish between, expected, unexpected positive, and unexpected negative changes. An unexpected negative change raises uncertainty by 1.02 times its square, thus lowering output through the coefficient on uncertainty (-1.36). It also lowers output the following period through the coefficient on the lagged real exchange rate (0.34) and due to the persistence of the shock in raising uncertainty. An unexpected positive change will also raise uncertainty and lower output through the coefficient on uncertainty, but now the negative effect will be partly offset by an increase in output the following period due to the positive coefficient on the lagged real exchange rate. The length of time that output is affected depends on the persistence of uncertainty, and the autoregressive terms in the output growth equation.[13] Figure 3 demonstrates the simulated effect of a one time, 5-percentage point, unexpected, increase in the real exchange rate on uncertainty and output growth. Output growth is sharply negative, then converges back to its long run equilibrium in an oscillatory manner. In contrast, a 5-percentage point increase in the real exchange rate that was anticipated would have no effect on uncertainty and would raise output by 1.7 percentage points in the following period.

However, we have argued that even predictable exchange rate swings may affect uncertainty, in that higher real exchange rates raise the possibility of a nominal devaluation. We now incorporate this possibility (that the level of the exchange rate affects the conditional variance of the exchange rate) into our MGARCH-M model. Table 3 presents our estimates of the MGARCH-M system described in equations 1, 2*, 3, 4, & 5 above. The only difference between this model and the previous one is that we now allow the level of the real exchange rate to affect the conditional variance of the real exchange rate.

This experiment is contained in equation 2* of Table 3, where the lagged real exchange rate has a coefficient of 0.03 and a t-statistic of 3.21. In Mexico, during our 1971 - 1996 sample, ***higher real exchange rates produce greater exchange rate uncertainty***. This result supports our extension of Ball's model to real exchange rates. The rest of the results in Table 3 are almost identical to those in Table 2. Most importantly, exchange rate uncertainty is still a negative and significant determinant of industrial production growth and the levels, squares and cross-products of the residuals still contain no patterns.

In this model, even anticipated increases in the real exchange rate now raise uncertainty (with a coefficient of .02) which lowers output growth (by a coefficient of -1.34). Also, just like in Table 2, the anticipated increase raises output growth in the next period (by a coefficient of 0.34). Thus in Table 3, anticipated real exchange rate increases raise output growth less, and unanticipated real exchange rate increases lower output growth more, than in the standard model in Table 2.

In Table 4 we re-estimate the model of Table 2 over the first half of the sample only (1971 - 1983). We find the same key result, that exchange rate uncertainty significantly lowers output growth, though the significance level drops to 0.05. While the significant influence of US growth on Mexican growth does not appear in these early data, the rest of the variables work largely as they do in the full

13. An anticipated exchange rate change does not affect uncertainty and thus will affect output with a lag according to the coefficient on the lagged exchange rate and the autoregressive components of the output equation.

sample equation, though with generally lower t-statistics.[14] We thus find that our results on the negative growth effects of exchange rate uncertainty appear in the data even when we exclude the years covering the structural reform and opening of the Mexican economy that occurred in the late 1980's.

VII. Conclusion

We show for the case of Mexico that (1) real exchange rate uncertainty adversely affects output growth, and (2) a higher real value of the peso raises exchange rate uncertainty. These results are novel in that they contain the first demonstration of a link between the level and degree of uncertainty for the real exchange rate; the first GARCH-M time series demonstration of a negative relation between real exchange rate uncertainty and economic growth; and the first demonstration of an RER uncertainty - growth length that controls for trade.

These results are also important, because they indicate that the general exchange rate policy followed by the Mexican government, fixing the nominal exchange rate but failing to control inflation, which produces an appreciating real exchange rate, has been somewhat counterproductive. Our results imply that stabilizing the real, rather than nominal exchange rate is may be a preferable goal for national exchange rate policies.

There is much work remaining to be done to generalize these results. However, future studies of the real effects of exchange rate uncertainty should consider the possibility that high real exchange rates are more uncertain than lower real exchange rates. They should also control for the effect of exports on growth when testing whether RER uncertainty has an independent negative effect on overall economic activity. Finally given the convincing demonstrations that exchange rates are conditionally heteroskedastic, future work should eschew the use of cross sectional tests that implicitly assume the error variance of the exchange rate is constant over time within each country.

14. Neither the AR or MA terms at the 10th lag in the RXR equation are at all significant in this restricted sample and are thus dropped from the model reported in Table 3.

Table 1. Recent Empirical Studies

Author	Countries	Results	ER Volatility Proxy
A. Trade			
DeGrawe & Vefaille (1988);	15 industrial countries	Inconclusive	Variance of ER (cross-sectional)
Bini (1991);	European Mon. Union	Significant	
Savvides (1992);	62 industrial and developing countries	Inconclusive	
Frankel & Wei (1993)	63 industrial and developing countries	Inconclusive	
Koray & Lastrapes (1989);	5 industrial countries	Inconclusive	Moving Standard Deviation (time series)
Mann (1989);	USA, Japan & Germany	Inconclusive	
Lastrapes and Koray (1990)	5 industrial countries	Inconclusive	
Bailey and Tavlas (1988);	USA	Not significant	ER misalignment (time series)
Perée & Steinherr (1989)	5 industrial countries	Inconclusive	
Bélanger et al (1992)	Canada and USA	Inconclusive	Difference between actual and forward ER (time series)
Feenstra & Kendall (1991);	UK, Japan & Germany	Significant for UK & Germany	Generate ER volatility series using ARCH/GARCH models
Arize (1993)	7 industrial countries	Significant	
Kroner & Lastrapes (1993)	5 industrial countries	Significant	
B: Growth			
Cottani, Cavallo &Khan (1990)	24 LDC's	Significant	Coefficient of variation of RER.
Mendoza (1997)	40 industrial and developing countries	Significant	Standard deviation of terms of trade (cross-section)

Table 2: Real exchange rates and industrial production growth in Mexico, 1971.01 - 1996.11: Real exchange rate uncertainty lowers economic growth

Simultaneous GARCH-M system with constant conditional correlations

$$RXR_t = \underset{(9.78)}{38.08} + \underset{(3.37)}{.25}\,RXR_{t-1} + \underset{(2.64)}{.51}\,RXR_{t-2} + \underset{(2.83)}{.21}\,RXR_{t-5} - \underset{(3.58)}{.17}\,RXR_{t-6} - \underset{(4.76)}{.05}\,RXR_{t-10} - \underset{(7.12)}{.039}\,Trend$$

$$+ \underset{(5.27)}{.71}\varepsilon_{t-1} - \underset{(2.12)}{.12}\varepsilon_{t-3} + \underset{(3.00)}{.15}\varepsilon_{t-6} + \underset{(2.37)}{.040}\varepsilon_{t-10} + \underset{(1.14)}{.17}\sigma^2_{\varepsilon t} - \underset{(2.02)}{.074}\sigma^2_{vt} + \varepsilon_t \quad (1)$$

$$\sigma^2_{\varepsilon t} = \underset{(3.66)}{2.09} + \underset{(4.98)}{1.02}\varepsilon^2_{t-1} + \underset{(2.05)}{.153}\,\sigma^2_{\varepsilon t-1} \quad (2)$$

$$Y_t = -\underset{(1.73)}{28.91} - \underset{(8.61)}{.56}Y_{t-1} - \underset{(3.28)}{.19}Y_{t-2} - \underset{(3.70)}{.18}Y_{t-7} - \underset{(5.78)}{.27}Y_{t-8} + \underset{(2.54)}{.44}YUSA_{t-1} + \underset{(4.02)}{.34}\,RXR_{t-1}$$

$$+ \underset{(3.15)}{.16}\,Exports_t - \underset{\boldsymbol{(3.68)}}{\boldsymbol{1.36}}\boldsymbol{\sigma^2_{\varepsilon t}} - \underset{(0.13)}{.034}\sigma^2_{vt} + v_t \quad (3)$$

$$\sigma^2_{vt} = \underset{(7.29)}{733.7} + \underset{(2.59)}{.26}\,v^2_{t-1} \quad (4)$$

$$COV_t = -\underset{(1.43)}{.089}(\sigma_{\varepsilon t}\sigma_{vt}) \quad (5)$$

Residual Diagnostics

	RXR	Y	Cross
Q(5)	1.24	4.75	3.55
Q(10)	3.05	6.78	9.08
Q(20)	9.17	15.81	15.06
$Q^2(5)$	0.09	2.04	
$Q^2(10)$	0.24	7.54	
$Q^2(20)$	0.44	19.23	

Log of the Likelihood Function: -2370

The sample is 311 monthly observations from 1971.01 - 1996.11. RXR is the real exchange rate, Y is the growth of industrial production, YUSA is the growth of US industrial production, Trend is a linear trend, and Exports is a 6 month moving average of export growth. Numbers in parentheses are t-statistics. The critical values at the 0.05 level for both the Q and Q^2 stats are 11.70, 18.31 and 31.41 at 5, 10, and 20 lags. The maximization method is BHHH.

Table 3: Real exchange rates and industrial production growth in Mexico, 1971.01 - 1996.11: Higher real exchange rates raises exchange rate uncertainty

Simultaneous GARCH-M system with constant conditional correlations

$$RXR_t = \underset{(9.30)}{24.17} + \underset{(3.10)}{.52}\, RXR_{t-1} + \underset{(2.68)}{.45}\, RXR_{t-2} + \underset{(2.72)}{.14}\, RXR_{t-5} - \underset{(3.57)}{.14}\, RXR_{t-6} - \underset{(4.73)}{.12}\, RXR_{t-10} - \underset{(6.47)}{.023}\,Trend$$

$$+ \underset{(5.25)}{.69}\varepsilon_{t-1} - \underset{(2.22)}{.12}\varepsilon_{t-3} + \underset{(2.95)}{.093}\varepsilon_{t-6} + \underset{(2.24)}{.042}\varepsilon_{t-10} - \underset{(1.02)}{.15}\sigma^2_{\varepsilon t} - \underset{(1.98)}{.072}\sigma^2_{vt} + \varepsilon_t \qquad (1)$$

$$\sigma^2_{\varepsilon t} = \underset{(3.61)}{\boldsymbol{.021}}\, \boldsymbol{RXR_{t-1}} + \underset{(4.66)}{1.04}\varepsilon^2_{t-1} + \underset{(1.86)}{.14}\,\sigma^2_{\varepsilon t} \qquad (2)$$

$$Y_t = \underset{(1.70)}{-28.25} - \underset{(8.39)}{.55}Y_{t-1} - \underset{(3.24)}{.19}Y_{t-2} - \underset{(3.74)}{.18}Y_{t-7} - \underset{(5.73)}{.27}Y_{t-8} + \underset{(2.57)}{.45}YUSA_{t-1} + \underset{(4.01)}{.34}\, RXR_{t-1}$$

$$+ \underset{(3.31)}{.17}\, Exports_t - \underset{(3.89)}{\boldsymbol{1.34}}\boldsymbol{\sigma^2_{\varepsilon t}} - \underset{(0.02)}{.008}\sigma^2_{vt} + v_t \qquad (3)$$

$$\sigma^2_{vt} = \underset{(8.41)}{731.6} + \underset{(2.63)}{.27}\, v^2_{t-1} \qquad (4)$$

$$COV_t = -\underset{(1.37)}{.088}(\sigma_{\varepsilon t}\sigma_{vt}) \qquad (5)$$

Residual Diagnostics

	RXR	Y	Cross
Q(5)	1.27	5.03	3.55
Q(10)	3.13	7.36	8.87
Q(20)	9.24	16.16	14.81
$Q^2(5)$	0.10	1.91	
$Q^2(10)$	0.26	6.94	
$Q^2(20)$	0.47	17.86	

Log of the Likelihood Function: -2359

The sample is 311 monthly observations from 1971.01 - 1996.11. RXR is the real exchange rate, Y is the growth of industrial production, YUSA is the growth of US industrial production, Trend is a linear trend, and Exports is a 6 month moving average of export growth. Numbers in parentheses are t-statistics. The critical values at the 0.05 level for both the Q and Q^2 stats are 11.70, 18.31 and 31.41 at 5, 10, and 20 lags. The maximization method is BHHH.

Table 4: Real exchange rates and industrial production growth in Mexico, 1971.01 - 1983:12 Real exchange rate uncertainty still lowers economic growth

Simultaneous GARCH-M system with constant conditional correlations

$$RXR_t = \underset{(3.75)}{38.10} + \underset{(0.82)}{.22}\, RXR_{t-1} + \underset{(2.09)}{.51}\, RXR_{t-2} + \underset{(2.44)}{.21}\, RXR_{t-5} - \underset{(1.83)}{.17}\, RXR_{t-6} - \underset{(2.82)}{.039}\, Trend$$

$$+ \underset{(2.79)}{.71}\varepsilon_{t-1} - \underset{(1.39)}{.12}\varepsilon_{t-3} + \underset{(2.18)}{.153}\varepsilon_{t-6} + \underset{(0.65)}{.12}\sigma^2_{\varepsilon t} - \underset{(0.45)}{.009}\sigma^2_{vt} + \varepsilon_t \qquad (1)$$

$$\sigma^2_{\varepsilon t} = \underset{(1.34)}{.791} + \underset{(3.11)}{1.18}\varepsilon^2_{t-1} + \underset{(2.55)}{.27}\,\sigma^2_{\varepsilon t} \qquad (2)$$

$$Y_t = \underset{(0.89)}{-31.26} - \underset{(5.68)}{.51}Y_{t-1} - \underset{(2.20)}{.19}Y_{t-2} - \underset{(2.87)}{.22}Y_{t-7} - \underset{(3.43)}{.22}Y_{t-8} + \underset{(0.91)}{.21}YUSA_{t-1} + \underset{(1.88)}{.43}\, RXR_{t-1}$$

$$+ \underset{(2.69)}{.23}\, Exports_t - \underset{\mathit{(2.33)}}{\boldsymbol{1.01}}\boldsymbol{\sigma^2_{\varepsilon t}} - \underset{(0.86)}{.452}\sigma^2_{vt} + v_t \qquad (3)$$

$$\sigma^2_{vt} = \underset{(5.50)}{684.5} + \underset{(2.24)}{.33}\, v^2_{t-1} \qquad (4)$$

$$COV_t = - \underset{(0.49)}{.059}(\sigma_{\varepsilon t}\sigma_{vt}) \qquad (5)$$

Residual Diagnostics

	RXR	Y	Cross
Q(5)	6.52	2.97	2.29
Q(10)	9.95	5.73	5.681
Q(20)	15.35	8.93	16.36
$Q^2(5)$	0.26	5.15	
$Q^2(10)$	0.57	7.33	
$Q^2(20)$	1.30	21.71	

Log of the Likelihood Function: -1187

The sample is 156 monthly observations from 1971.01 - 1983.12. RXR is the real exchange rate, Y is the growth of industrial production, YUSA is the growth of US industrial production, Trend is a linear trend, and Exports is a 6 month moving average of export growth. Numbers in parentheses are t-statistics. The critical values at the 0.05 level for both the Q and Q^2 stats are 11.70, 18.31 and 31.41 at 5, 10, and 20 lags. The maximization method is BHHH.

Appendix 1: Summary Statistics

Variable	Mean	Std. Deviation
Mexican IP growth (Y)	4.02	38.99
US IP growth (USA)	2.86	9.68
Real Export growth (Exports)*	9.01	149.60
Mexican Real Exchange Rate (RXR)	120.55	21.59

Mexican IP, exports, and price level (used to deflate nominal exports) are from the IMF's IFS CD-ROM. US IP is from CITIBASE. Mexican real exchange rate is from JP Morgan (www.jpmorgan.com).

* The variable used in the MGARCH-M models in the paper is a six month moving average of real export growth.

Appendix 2.
Stationarity Tests

Here we report the results of ADF tests containing a linear trend and from 1 to 12 lagged difference terms for the 4 key variables of the model.

#lagged differences	Mexican real exchange rate	Mexican IP	Mexican real	US IP exports
1	-3.68*	-2.64	-2.54	-3.23
2	-3.43*	-2.24	-2.04	-3.52*
3	-2.89	-2.71	-1.85	-3.31
4	-3.02	-2.81	-1.43	-3.21
5	-3.92*	-2.73	-1.38	-2.91
6	-4.20**	-2.77	-1.17	-2.63
7	-3.89*	-2.77	-0.90	-2.60
8	-4.00**	-2.24	-1.04	-2.57
9	-4.41**	-2.36	-1.18	-2.72
10	-4.37**	-2.38	-1.07	-2.76
11	-4.31**	-2.49	-0.98	-2.43
12	-4.48**	-2-74	-1.06	-1.94

* and ** indicate rejection of the null hypothesis of a unit root in the series at the .05 and .01 levels respectively. The three series that are non-stationary in the levels are stationary in the first differences. In each case, ADF tests on the differences reject the null of a unit root at the .05 level at every lag from 1 to 12.

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Figure 1. The estimated conditional standard deviation of the real exchange rate, 1971 - 1996

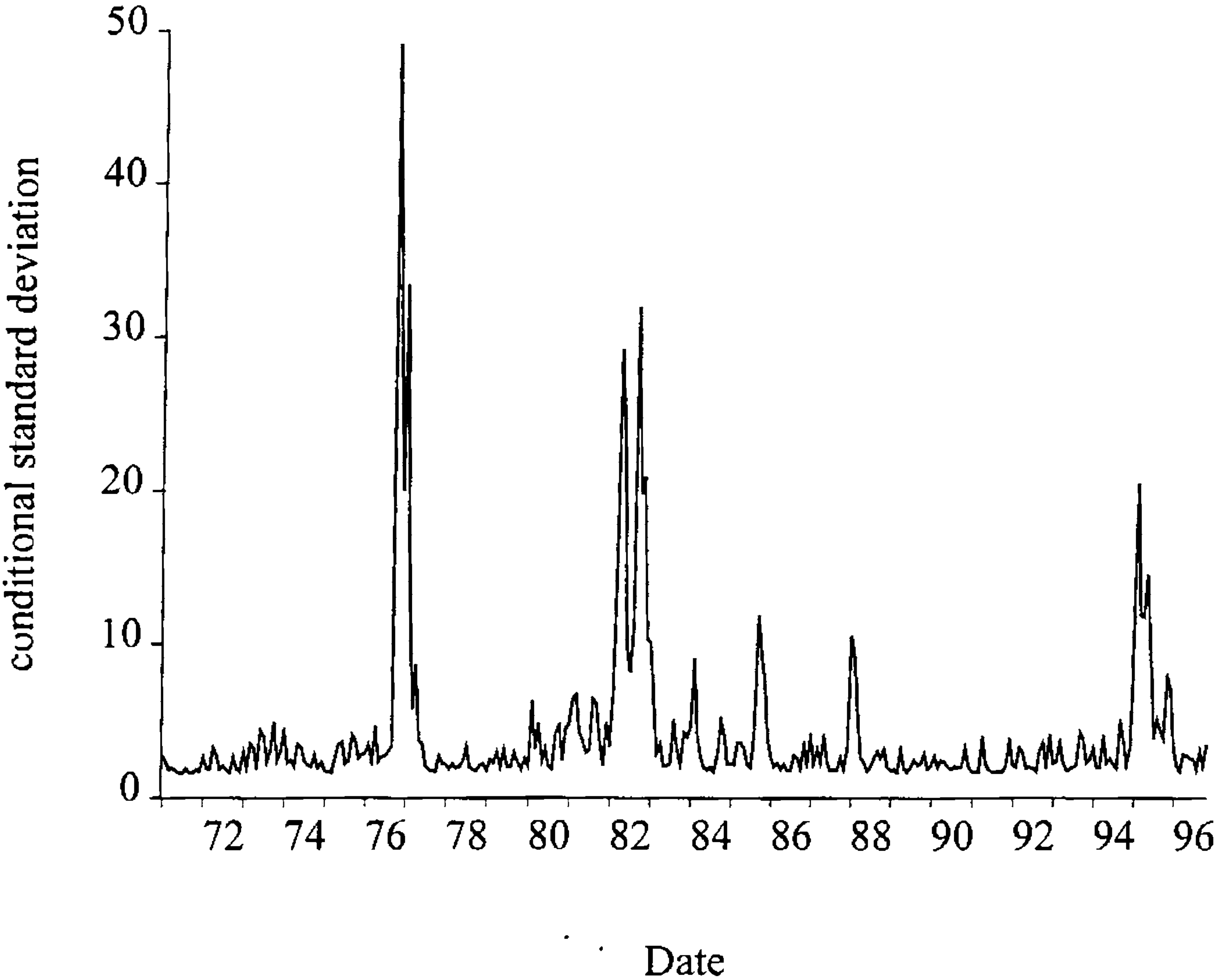

Figure 2. The estimated conditional standard deviation of industrial production growth, 1971 - 1996

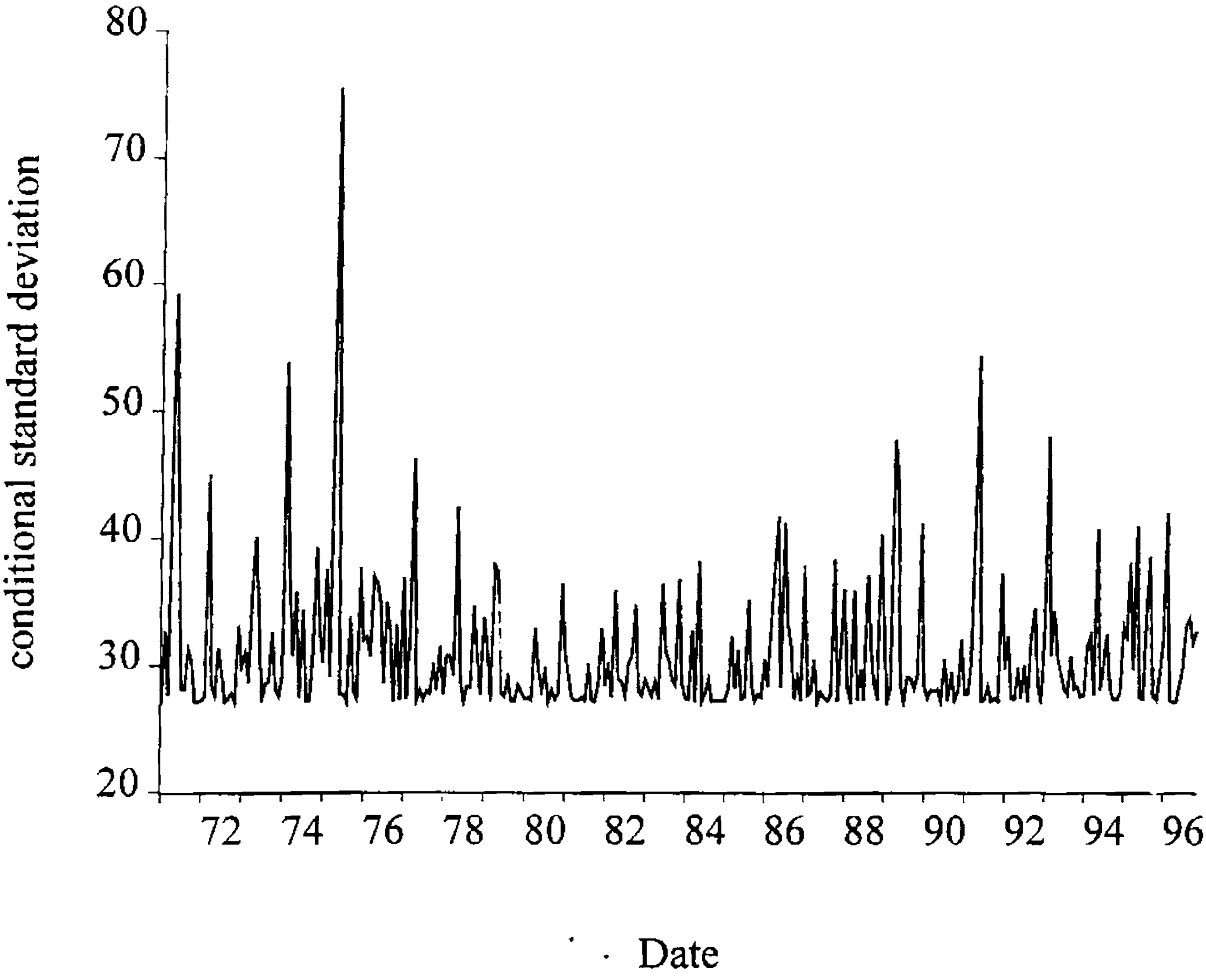

Figure 3. The response of exchange rate uncertainty and ouput growth to a one - time, positive innovation in the real exchange rate