How Does the Monetary Model of Exchange Rate Determination Look When It Really Works?

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Abstract

This paper shows that the Mexican economy from 1945 to 2002 is, like the German hyperinflation period, a unique monetary "natural experiment," where fundamental relationships, like money demand, PPP and the monetary model of exchange rate determination can be analyzed with unparalleled clarity. They hold for the whole period and nonoverlapping subsamples. The long span and a conspicuous structural change might be useful in explaining why these theoretical relationships are hard to prove elsewhere. A stunning switch in the weak exogenity properties helps to clarify simultaneously the controversies surrounding the exchange rate forecastability and the absence of money in models of inflation.

Keywords: Cointegration, Weak Exogeneity, Exchange Rate Forecasting, Invertible Money Demand, Inflation.

JEL classifications: C51, C52, E30, E41,F43

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1 Introduction

The objective of this article is to show an unusual case where the simplest monetary model of exchange rate determination ("the monetary model," for short) and the basic assumptions behind it, money demand and purchasing power parity (PPP), hold for short and long spans of time. Similar cases seem rare enough to make some authors believe that these relationships "are unlikely to hold at each point in time" (Rapach and Wohar, 2001a). The usefulness of our results go beyond the simple demonstration of the applicability of an important model to a real situation. The Mexican case can be regarded as a monetary "natural experiment" where some important propositions can be tested in the context of simple linear models.

The monetary relationships in Mexico work amazingly well for the whole sample and for periods of low and high inflation without the problems of signs that have afflicted many other studies. The dynamic aspects of each relationship are analyzed in light of a conspicuous one-time change that occurred in 1982. The results help in understanding why the monetary fundamentals can be useful or not in econometric models to forecast the nominal exchange rate or the path of inflation. These issues can be studied together in a natural way if the monetary model really works.

The monetary model has been a favorite topic in the field of International Economics since the end of the Breton Woods period. The model states the existence of a long-run equilibrium relationship among relative money supplies, relative income levels and the nominal exchange rate although other variables are often included. Because its empirical support from individual time series has been mixed at best, new approaches to test it are constantly springing up. Recent attempts have claimed more success and they tend to mimic those in the PPP literature. They include the study of panels for the post-Breton Woods period (Groen, 2000 and Mark and Sul, 2001) and time series that span more than a century (Rapach and Wohar, 2001). The application of nonlinear methods is an active area of research too (Ma and Kanas, 2000).

So far, the main conclusions from this modern literature are that, although panel data analysis seems supportive of the model, the resilient failure in individual cases and the rejection of the homogeneity assumption makes the applicability of the model dependent on the researcher's prior beliefs (Rapach and Wohar, 2001b). On the other hand, the study of long time series has provided some cases where the model seems to work (Rapach and Wohar, 2001a). However, in no case has the evidence attained "beyond reasonable doubt" the long-pursued objective of forecasting the nominal exchange rate on the basis of monetary fundamentals (Neely and Sarno, 2002).

The empirical work has been based on the estimation of a reduced-form relationship because the researcher hopes that any problems in proving each structural equation will cancel out. This paper takes a completely different approach. It carefully analyzes an individual case and demonstrates that the monetary model and its building parts work in a precise fashion for both short and long spans of time. The equations fit the Mexican data from 1945 to 2000 with great accuracy in spite of a conspicuous break in 1982. The key ingredient for the success of the monetary model in Mexico is the high speed of convergence.

We show that the PPP condition and two versions of the monetary model hold for the whole sample, but that a one-time change in the dynamics of the system and, probably, in the long-run parameters occurred in 1982. Because of this, there is not a simple error correction model with a constant feedback parameter for any variable (except real money) that covers the whole sample. During the 1945-1981 period, nominal money is weakly exogenous with respect to the price level and the exchange rate. The price level, in turn, is weakly exogenous with respect to the nominal exchange rate. During this period, the exchange rate is forecastable on the basis of the information contained in either the monetary fundamentals or the relative prices (but not both). There is an error-correction model for the price level associated to the money demand. For the nominal exchange rate there are error-correction mechanisms that come from the PPP condition and any version of the monetary model.

For the 1983-2000 subsample, the exchange rate becomes weakly exogenous with respect to prices and money and, therefore, is not forecastable based on these variables. There is one error-correction model for prices that comes from the PPP condition (instead of the money demand as in the previous period) and there are three error-correction models available for nominal money (from the money demand equation and the two versions of the monetary model). This is a period where the money demand is noninvertible and the exchange rate is nonpredictable in spite of the existence of a monetary equilibrium relationship. It is argued that the changes in the dynamic properties are an implication of forward-looking behavior in face of some drastic events and policy turns.

The rest of the document is organized as follows: in section 2 the data are described and their integration properties examined; section 3 provides a graphical preliminary analysis; section 4 presents a summary of the problems found in empirical applications of the monetary model; section 5 analyzes the long-run relationship among money, prices and the exchange rate for the whole sample; section 6 analyzes the long-run relationships and the adjustment dynamics that results from splitting the sample; section 7 provides an interpretation of the results and; section 8 gives the conclusions.

2 Description of Variables and Unit Root Tests

The data sources are not homogeneous. Ideally, the analysis would have been carried out only in quarterly frequency but that is not feasible due to the lack of this type of information for the GDP or the index of industrial production for a big part of the sample. On the other hand, due to a structural change, using annual data for the whole analysis is not possible because there would be not enough observations in one of the subsamples for some important tests. Unless otherwise stated, the analysis for the whole sample and the 1945-1981 period is carried out with annual data while for the 1983-2000 period the data are quarterly.

Another data problem is that the consumer price index began to be reported in 1969 and it will be used for the analysis with quarterly data. Before that year, the inflation measure was based on the wholesale price index of Mexico City. This index began in 1932 and it will be used whenever annual data is needed. During the time when both indexes are available they show very similar behavior. The symbol P will be used in both cases. The monetary aggregate (M) for both annual and quarterly data is currency. The interest rate (i) is the one-month Mexican Treasury Bonds rate. Unit labor costs (W) are measured by the index of average total remunerations for the manufacturing sector which has been available also since 1969. The exchange rate (E) is defined as pesos per dollar (an increase means a depreciation). The measure of the foreign price level is given by the US consumer price index P^{us}.

For annual data the scale variable is GDP while for quarterly data it is the index of value of industrial production (Y). Whenever needed, I converted all monthly series into quarterly frequency by taking the end-of-quarter observation. I use small letters to represent the logs of the series. Table 1 presents the ADF unit root tests for annual (1945-2000) and quarterly data (1980-2000). Significance at the 1%, 5% and 10% levels are indicated by the superscripts a, b and c, respectively.

—TABLE 1 ABOUT HERE—

According to the results of the table, all the variables appear to be $I(1)$ but there are some borderline cases such as inflation, the interest rate and the real exchange rate. The case of the real exchange rate is especially interesting because it is an $I(0)$ process even with the short 1980-2000 sample, unlike what happens with many other currencies. The stationarity of the real exchange rate in Mexico has been pointed out before by several economists (for example, Lee (1999) and Noriega and Medina (2000)).

3 Preliminary Analysis

This section sketches some of the ideas that motivate the econometric analysis. Special emphasis is given to the identification of a one-time structural change of several relationships. A first perspective about the relationship among money, prices and the exchange rate can be obtained by observing in table 2 the descriptive statistics for three samples of some variables.

—–TABLE 2 ABOUT HERE—–

For the three samples, the mean for average inflation is nearly equal to the sum of average foreign inflation and average depreciation. This is just a consequence of the strong mean-reversion of the real exchange rate. The real exchange rate turns out to be 20% more depreciated in the second part of the sample. The speed of adjustment (not reported in the table) is also higher in the second subsample. The half-life of a real exchange rate deviation for the whole sample is two years; for the 1945-1981 subsample, it is 2.9 years while for the 1983-2000 period it is barely 1.1 years. Compare this with the three to five year "consensus" figure for most countries reported by Rogoff (1996). It can also be seen that the average rate of growth of money is approximately equal to the average rate of growth of real output, plus either average domestic inflation or the sum of average foreign inflation and average depreciation.

Another perspective is provided by the four panels of figure 1. The first one shows the log of the nominal exchange rate; the second displays the log of real money balances $(m - p)$ with a continuous line and the log of real GDP (plus a constant) with a dashed line; the third panel shows the annual inflation rate and the real exchange rate; the fourth, the levels of seigniorage and the real exchange rate. The sample goes from 1940 to 2000. In all graphs there is a vertical line at the year 1982 to indicate a structural change that the econometric analysis takes into consideration.

—–FIGURE 1 ABOUT HERE—–

The first graph recapitulates part of the long history of instability of the Mexican peso across several types of exchange rate systems. The steepest part of the line begins in 1982 and ends in 1987. The second panel indicates that from 1945 until 1981, there was a proportional relationship between the logs of real money balances and real GDP. The velocity of money was nearly constant during that period. The third panel shows that the real exchange rate and the inflation rate were relatively stable from the fifties until the beginning of the seventies. The rate of inflation matches very closely the movements of the real exchange rate, especially since 1982.

The fourth panel shows how the seignoriage[1] began to grow strongly in 1972 and, at the same time, the real exchange rate began to appreciate, ending its long period of stability. The shape of the seigniorage path looks very similar to that of inflation for most of the sample except during the 1995 crisis. The increase in inflation and seigniorage that started in 1970 and peaked in 1975 were the most important causes of the ensuing devaluations of 1976 and 1977, after the depletion of the Central Bank reserves made it impossible to keep the parity. The process that led to the 1982 devaluation was similar. However, since 1983, the real exchange rate has always preceded periods of inflationary money growth.

The expansion of the money supply during the seventies and eighties was closely related to the increase of the financial requirements of the public sector as a percentage of GDP. From 1965 to 1971, this public finance indicator averaged 0.7%. From 1972 to 1976 it averaged 7.8% and from 1981 to 1986 it jumped to 13.2% (Gil-Diaz and Ramos-Tercero (1988)). The Mexican Central Bank obtained its legal independence in 1993 and that might help to explain why the 1995 devaluation did not increase the level of seigniorage despite the fact that inflation went up sharply. The peak of seigniorage in 1999 was due to an abnormal and temporary increase in the demand for cash in view of the Y2K problem. The graphs indicate that a big change in

[1] Defined as $(M_t - M_{t-1})/P_{t-1}$. To be precise, much of the money growth during the fixed exchange rate period was simply a loss of reserves from the Central Bank while for the period of intermediate regimes most of it was inflation revenue.

several economic relationships took place in 1982. The event that catalyzed the change was the debt crisis. The Mexican government made some drastic modifications to its economic policy and the behavior of some variables changed accordingly. For example, real money was proportional to real output until 1981 but not afterwards (second panel of figure 1). Simultaneously, with the exacerbation of the inflationary environment, the money demand parameters seem to have changed.

The 1982 debt crisis started after a strong increase in the interest rates that the government and domestic firms were paying on a large stock of foreign liabilities. This event coincided with a period of plunging prices for oil, by then Mexico's main export product. The financial problems caused a strong contraction of economic activity. Fiscal resources were difficult to obtain by taxes on income or consumption because of political pressures and, therefore, inflation went up.

4 The Monetary Model of Exchange Rate Determination

The monetary model rests on the following equations:

$$m - p = \theta_y \, y - \theta_r \, r \tag{1}$$

$$m^* - p^* = \theta_{y^*} \, y^* - \theta_{r^*} \, r^* \tag{2}$$

$$p = e + p^* \tag{3}$$

$$i = i^* + E[\pi] \tag{4}$$

where m, p, y and i are the money supply, the price level, real income and the nominal interest rate of the domestic country, respectively. The starred variables denote the corresponding variables for the foreign country. The symbol e denotes the nominal exchange rate.

The first two equations are the money demand functions for the home and foreign country, respectively; the third is the PPP condition and the fourth one is the UIC. From these equations, a single expression that links the nominal exchange rate with relative money supplies and relative income can be obtained:[2]

$$e = (m - m^{*}) - \theta_y (y - y^{*}) \tag{5}$$

If the system holds in the sense that the residuals of equations 1-4 are all $I(0)$ then some of the variables will adjust to eliminate possible shocks. An intermediate form between the monetary model and the PPP condition is the following:

$$m = \theta_y \, y + e + p^{*} \tag{6}$$

which has not received much empirical attention although, in principle, it should be easier to test than the pure monetary version. Although in the derivation equation 5 it seems natural to assume that all the equilibrium relationships are met, in practice it is believed that the conditions "... at the core of the monetary model are unlikely to hold at each point in time, [therefore] the monetary model should be viewed as a long-run or steady-state model of exchange rate determination."[3]

The static equations 1-5 above are long-run equilibrium conditions identified with cointegration relationships in empirical work. However, what has galvanized interest in the model is a dynamic question: can the nominal exchange rate be forecast on the basis of monetary fundamentals or relative prices? Many researchers have been looking for a positive answer. However, beginning with the famous finding that a model of this kind could not beat a random walk (Meese and Rogoff, 1983), all attempts, even recent ones with panel data and very long time series "have failed to establish the existence of predictability beyond reasonable doubt (Neely and Sarno, 2002). In principle, any of the variables in the system could respond to the disequilibrium and, because of that, to be forecast but the empirical research has focused exclusively on the nominal exchange

[2]The derivation assumes that the money demand parameters are equal and that there is forward looking behavior.
[3]Rapach and Wohar (2002).

rate.

Weak exogeneity implies that the lagged residuals from a long-run equilibrium relationship will not have explanatory power in a short-run regression of a variable with that property. It is said then that such a variable is not Granger-caused in the long-run by the other variables in the system (see Hatanaka 1996). Although cointegration relationships are invariant to the variables excluded from the system, the dynamic properties are not and, therefore, the inclusion of more nonstationary variables could make one variable classified before as "weakly exogenous" change its status. This paper presents some examples of this fact.

Even if a long-run relationship for monetary fundamentals and the exchange rate is proved to exist, that does not assure that the latter will be predictable based on monetary fundamentals or relative prices. The reason is provided by the present value model proposed by Campbell and Shiller (1987): the information set available for the econometrician is narrower than the one available for the market. Because of that, financial variables in efficient markets such as stock prices or the exchange rate tend to be classified as exogenous by statistical tests and, therefore, impossible to forecast based on the information typically available to the econometrician. The study of the dynamics of the system (1)-(6) should be in theory the basis of the joint analysis of nominal variables in an open economy. However, the monetary model has been used mainly to try to forecast the exchange rate while the analysis of inflation has been based on other types of models.

5 Analysis For the Whole Sample (1945-2000)

The empirical analysis begins with the estimation of three long-run relationships for the nominal exchange rate that work for the whole sample. They are approximately equivalent and generally they should hold jointly. Equally interesting, the dynamics shows a rather peculiar change around 1982. To take this into consideration it is necessary to understand the behavior of each variable. Although the analysis is carried out with single-equation models, similar results can be obtained in a VAR framework.

5.1 Long-Run Monetary Relationships For the Exchange Rate

The first long-run relationship for the nominal exchange rate is the PPP condition (equation 3) and the second one is the monetary model (equation 5). The third relationship being estimated is equation (6) which combines domestic monetary variables with the foreign price level. Almost all the results, except those for the 1983-2000 period, can be obtained with any definition of narrow money. Both M1 and currency are used, although the latter is preferable because it produces more stable money demands in all subsamples.

5.1.1 PPP

The PPP condition has already been proved by showing in table 1 that the real exchange rate is stationary even for the short subsample. More intriguing is the fact that some tests applied to the short period of free floating exchange rate 1995-2001 (with monthly data) still reject the presence of a unit root at the 1% level of significance.[4] That PPP holds independently of the exchange rate system and the degree of openness of the economy (Mexico opened itself to foreign trade in 1985) suggests that the equilibrium in asset markets interpretation of the property is preferable to the most typical alternative based on arbitrage of commodities. The first view proposes the use of broader price indexes while the second suggests indexes of traded goods.[5] Other tests provide even stronger evidence in favor of the stationarity of the real exchange rate but we will skip them given that that result has been reported by several other authors. The first long-run equation for the nominal exchange rate is:

[4]For example, an unrestricted error-correction model for inflation applied to the period that goes from June 1995 to December 2001 still recovers the long-run parameters of the PPP condition and shows cointegration at the 1% level

[5]See Frenkel (1977) for these and other issues related to PPP.

$$e_t = p_t - p_t^{us} + rer_t \quad (7)$$

where rer is the long-run equilibrium error or real exchange rate.

5.1.2 Two Versions of the Monetary Model

The next long-run relationship to be tested is the classical monetary model (5), which assumes unitary income elasticities in the money demand of both countries. I use M1 for Mexico and M2 for the US because that assumption is clearly met in the two cases.[6] The equilibrium relationship is the following:

$$e_t = (m1 - m2^{us})_t - (y - y^{us})_t + z_t^e \quad (8)$$

The ADF statistic for the residuals z_t^e of this equation is -3.11, which is to the left of the 5% level critical value (-2.92). This is a very popular specification that generally has not had luck but that in the Mexican case holds very easily.

For the other form of the monetary model (equation 6) the plug-in method provides weaker evidence so we resorted to direct estimation. From now on, unless otherwise stated, the definition of money will be currency.[7] In obtaining this equation we use the close relationship of the real exchange rate with inflation and, therefore, with the opportunity cost of holding money. The following unrestricted error-correction model is estimated:

[6] For Mexico, the long-run money demand for M1 that we estimated is $(m1 - p) = y - 1.2\Delta p + I(0)$. Mehra (1997) reports an elasticity of 1 for the demand for M2 in the US. The monetary aggregate for the US is that constructed by Bordo *et al.* (1998) which we completed using the rates of growth for M2 since 1996.

[7] This aggregate is the one that provides more stable money demands and also the one that is more closely related to the price level and economic activity in México. See Garces-Diaz (2003).

$$\Delta\widehat{(m-p)}_t = -0.55\,(m-p)_{t-1} - 0.54\,(e+p^{us}-p)_{t-1} + 0.46\,y_{t-1} - 4.7 \tag{9}$$

The t statistic for the lagged log of real money is used to test a relationship in the levels of real money, real income and the real exchange rate. To do this, we use the critical values of the Pesaran *et al.* (2001) procedure that allows the testing of a relationship of this sort regardless if the variables are $I(0)$ or $I(1)$. The t statistic is -4.28, which is to the left of the 1% critical value (-4.1) for the case where all the variables are $I(1)$. If all the variables are $I(0)$, then the critical value is more to the right (-3.43). Similarly, the F statistic is 6.9, which is larger than the critical value at the 1% level (6.36). The Jarque Bera statistic is nonsignificant at the 5% level so the residuals are normal. The evidence in favor of a long-run relationship is fairly strong. From this equation we can obtain the implicit long-run relationship:

$$(m-p)_t = 0.85\,y_t - (e+p^{us}-p)_t + z_t^m \tag{10}$$

where z_t^m is the equilibrium error. An interesting implication of this result is that the quasi-velocity of money $(p + 0.85\,y - m)$ is directly determined by the real exchange rate. From (9) and (10) we can obtain an expression analogous to equation (6):

$$m = 0.85\,y_t + (e+p^{us})_t + z_t^{m'} \tag{11}$$

where $z_t^{m'} = z_t^m - 2\,rer_t$ is clearly $I(0)$. Something intriguing about this procedure is that it still can work with small samples as long as PPP can be proved to hold as, for example, during the brief free-floating period 1995-2001.

The graphs in the first column of figure 2 show the fit of the three estimated relationships. The panels in the second column of graphs show the corresponding equilibrium errors. It can be seen that the relationship of the nominal exchange rate is tighter with relative prices (first panel) than with monetary fundamentals.

—–FIGURE 2 ABOUT HERE—–

The behavior of the equilibrium errors is very different for the two parts of the sample (split around 1982). In fact, the study of the dynamics can lead to wrong conclusions if one tries to estimate simple error-correction models for the whole sample as will be shown next.

5.2 Pitfalls in the Estimation of the Adjustment Dynamics

A sure mistake will occur if the change in the dynamics is not taken into consideration. For example, an error-correction model for the exchange rate during the 1983-2000 period is impossible to obtain no matter which variables are included. However, if a long enough sample that includes part of the 1945-1981 period is used to perform the estimation, then it will look as if the nominal exchange rate could be systematically predicted with very high precision even during the free-floating period (1995-2000). This mistake is present in Lee (1999) and several other authors.

Given the fact that the most important changes occurred in the weak exogeneity structure, it is very fortunate that for each cointegrating relationship there is only one variable which rejects that property. This fact allows efficient inference within the context of single equation models and, therefore, makes the presentation a lot simpler.

5.2.1 Pitfalls in the Estimation of Inflation Dynamics

Although similar results hold for each of the long-run relationships above, we will concentrate on the first of them. We estimated unrestricted error-correction models derived from the PPP condition for inflation and the depreciation rate. Equations (12a) and (12b) are error-correction models for inflation estimated for two different subsamples. The first one goes from 1948 to 2000 and the second from 1948 to 1981. Standard errors are in parentheses. The t statistic for the lagged level of the dependent variable can be used to test for cointegration but in this case the problems are very easy to spot.

$$\Delta\hat{p} = \begin{cases} \underset{(0.17)}{0.04}p_{t-1} - \underset{(0.17)}{0.04}(e+p^{us})_{t-1} + \underset{(0.12)}{0.72}\Delta p_{t-1} \quad 1945-2000 \qquad (12a) \\ \\ \underset{(0.15)}{0.30}p_{t-1} - \underset{(0.15)}{0.25}(e+p^{us})_{t-1} + \underset{(0.20)}{0.15}\Delta p_{t-1} \quad 1945-1981 \qquad (12b) \end{cases} \tag{12}$$

The t statistic of the lagged price level for both equations is nonsignificant at any level and, even worse, positive. If equation (12a) is interpreted mechanically, then it would be wrongly concluded that inflation does not react to the disequilibrium in any part part of the sample. However, the high pass-through in Mexico during the 1980-2000 period is well known. Equation (12b) is correct because it indicates that inflation did not respond to the disequilibrium errors during the 1945-1981 period.

5.2.2 Pitfalls in Equations for the Rate of Depreciation

The second set of equations corresponds to the nominal exchange rate. The first model is applied to the 1948-2000 period and the second to the 1983-2000 subsample.

$$
\Delta\hat{e} = \begin{cases} \underset{(0.27)}{0.95}p_{t-1} - \underset{(0.27)}{0.93}(e+p^{us})_{t-1} + \underset{(0.14)}{0.80}\Delta e_{t-1} \qquad 1945-2000 \qquad (13a) \\ \\ -\underset{(0.09)}{0.06}p_{t-1} + \underset{(0.09)}{0.05}(e+p^{us})_{t-1} + \underset{(0.15)}{0.18}\Delta e_{t-1} \qquad 1983-2000 \qquad (13b) \end{cases} \qquad (13)
$$

Equation (13a) shows a typical mistake in studies about Mexico that we commented on above. The t statistic of the lagged log of the nominal exchange rate is highly significant as it is lagged depreciation. However, equation (13b) shows that all variables are nonsignificant for the 1983-2000 period, which is the right result.

Something worth noticing is that in all the equations the right parameters of the PPP condition can be recovered from the coefficients of the lagged variables in levels. This is a further confirmation that a long-run relationship can hold even with a conspicuous change in the weak exogeneity properties.[8] As far as we know, this situation has never been reported in the literature and, because of its importance, will be examined with more detail in the next section.

6 Analysis of Subsamples

To split the sample and still show that the long-run relationships hold for each part is usually not done and it is only possible if the speed of adjustment is high enough. For example, the papers where PPP and the monetary model were shown to hold for some cases with very long time series (Taylor, 2000 and Rapach and Wohar, 2001, respectively) did not attempt it. The reasons might be the low speed of adjustment or that the relationships really did not hold after the end of Breton Woods. We split the sample and still can prove the existence of long-run relationships. More importantly, the right dynamics can only be obtained if

[8] An exception to this change in dynamics occurs in the case of equation 9. The reason for this arises from the special ordering of weak exogeneity among the variables that will be uncovered below.

the sample is divided in about 1982. For the 1945-1981 period the direction of long-run causality ran from money to prices to the exchange rate. For the 1983-2000 period the ordering is exactly the opposite.

6.1 The 1945-1981 Period

During this period the exchange rate was fixed but subject to recurrent devaluations. From 1954 to 1975 the parity was kept fixed and the average inflation level was the lowest in modern Mexican history.

6.1.1 The Long-Run Equilibrium Relationships During the 1945-1981 Period

Although a long-run relationship does not states causality, the equations are written with the weakly exogenous variables on the right hand side to emphasize the direction of this dynamic property. For this period, nominal money supply is the most exogenous of the variables and does not have an equation in terms of the others. To simplify notation, in each equation the long-run equilibrium errors are represented with the generic symbol $I(0)$. Unless otherwise stated, the cointegration vectors were obtained by means of unrestricted error-correction models and the existence of long-run relationships was tested using the method described in Pesaran *et al.* (2001).

$$p = \left\{ m - y + I(0) \right. \tag{14}$$

$$e = \begin{cases} (p - p^{us}) + I(0) & \text{(15a)} \\ (m_1 - m_2^{us}) - (y - y^{us}) + I(0) & \text{(15b)} \\ m - y - p^{us} + I(0) & \text{(15c)} \end{cases} \tag{15}$$

The price level is determined by the money supply in equation (14) while the nominal exchange rate can be expressed in terms of relative price levels or monetary fundamentals (equations 15a-15c), as in section 5.1.

The last of these relationships is obtained directly from (14) and (15a).

6.1.2 Adjustment Dynamics During the 1945-1981 Period

In principle, more than one of the variables in a long-run relationship could respond to the disequilibrium errors but that does not happen here. Each cointegration relationship has exactly one adjustment variable. This makes the statistical analysis simpler because it can be carried out within the context of single equation models.[9]

$$m \quad \left\{ \text{Weakly exogenous with respect to } p \textit{ and } e. \right.$$

$$\Delta\hat{p} = \begin{cases} -0.33\,(p - m + y)_{t-1} + 0.84\,\Delta m_t + 4.45 \\ p \text{ is weakly exogenous with respect to } e. \end{cases} \tag{16}$$

$$\Delta\hat{e} = \begin{cases} -0.70\,(e + p^{us} - p)_{t-1} + 0.32\Delta e_{t-1} + 1.94 & \text{(17a)} \\ -0.42(e - (m1 - m2^{us}) + (y - y^{us}))_{t-1} + 0.56\Delta e_{t-1} + 13.0 & \text{(17b)} \\ -0.59(e - m + y + p^{us})_{t-1} + 0.22\Delta e_{t-1} + 9.6 & \text{(17c)} \end{cases} \tag{17}$$

For the monetary aggregate an error-correction model does not exist because it is weakly exogenous with respect to the other variables. Although the price level appears in two relationships, there is only one error correction mechanism for inflation (associated to the money demand). For this period the money demand was invertible and, therefore, it could have been used to forecast inflation conditional on the monetary aggregate.[10] On the other hand, the price level is weakly exogenous with respect to the exchange rate in the PPP condition.

[9] Another alternative is the Johansen maximum likelihood approach. See Brüggemann (2002).

[10] To simplify the exposition, we restricted the coefficients of the lagged levels to match those of the money demand. However, the restriction is not accepted by the data. An unrestricted model that passes all the statistical tests is: $\Delta p_t = -0.58(p - 1.08(m - y))_{t-1} + 0.63\,\Delta m_t + 8.4$.

For the rate of depreciation, three equivalent error-correction models can be obtained. The first one comes from the PPP condition and the other two from the monetary models. Any of these equations could have been used to "forecast" the nominal exchange rate in the sense that it predicted a future devaluation (the exchange rate was fixed). Rejection of weak exogeneity for the exchange rate was found to be equivalent to its predictability within the context of long-run regressions in the cases examined by Rapach y Wohar (2001).

6.2 The 1983-2000 Period

During the 1983-2000 period the long-run relationships still hold but the adjustment dynamics runs in the opposite direction than the one in the previous period. The analysis is still feasible because the higher speed of adjustment of the real exchange rate compensates the smaller sample size (18 years versus 37 from the previous period).

6.2.1 The Long-Run Equilibrium Relationships for 1983-2000

The data are quarterly to obtain more flexibility with respect to annual frequency. The domestic scale variable is now the index of industrial production and the foreign monetary aggregate is $M1^{us}$. The long-run relationships are the following:

$$p = \left\{ e + p^{us} + I(0) \right. \quad (18)$$

$$m = \begin{cases} p + 0.5y - 0.5i + I(0) & \text{(19a)} \\ 0.91e + 0.57m1^{us} + 2.5y - 1.17y^{us} + I(0) & \text{(19b)} \\ 0.86(e + p^{us}) + 1.6y + I(0) & \text{(19c)} \end{cases} \quad (19)$$

Equation (18) is the PPP condition with a likely change in the mean of the real exchange rate. The left-hand side variable is now the price level. Equations (19a)-(19c) have different parameters from those of the previous period but this might be the result of the shorter estimation period. The three cases were written as equations for nominal money. Equation (19a) shows two changes in the long-run money demand. The first change is that the income elasticity falls from 1 to 0.5; the other change is that the opportunity cost variable has now a significant coefficient and, because of this, the velocity is no longer constant.

The first version of the monetary model requires the unrestricted estimation of the cointegration coefficients in order to to be proved. This is a consequence of the partition of the sample. Nonetheless, the most important parameter, the coefficient of the nominal exchange rate, is close to its theoretical value of 1 and the coefficients of the other variables have the correct sign and have reasonable magnitudes. The other version of the monetary model is in the same situation if it is estimated directly. However, it is possible to obtain parameters basically identical to the ones implied by theory (unit coefficient for the nominal exchange rate and an income elasticity equal to the one implied by the money demand) using the procedure applied in section 5.1. The details are available upon request.

6.2.2 Adjustment Dynamics for 1983-2000

The adjustment dynamics for this period is the mirror image of that from the previous period. Now the long-run causality runs from the exchange rate to prices to money. All the equations were estimated with seasonal dummies which are indicated with the generic symbol $Seas$.

$$e \quad \begin{cases} \text{Weakly exogenous with respect to } p \text{ and } m. \end{cases}$$

$$\Delta\hat{p} = \begin{cases} -0.14\,(p - e - pus)_{t-1} + 0.41\,\Delta p_{t-1} + 0.24\,\Delta(e + p^{us})_t + Seas \\ p \text{ is weakly exogenous with respect to } m. \end{cases} \tag{20}$$

$$\Delta\hat{m} = \begin{cases} -0.3\,(m - p - 0.5y + 0.5i)_{t-1} - 0.1\Delta i_{t-1} + Seas & \text{(21a)} \\ -0.3(m - 0.9e - 0.6m1^{us} - 2.5y + 1.2y^{us})_{t-1} + 0.56\Delta e_{t-1} + Seas & \text{(21b)} \\ -0.21(m - 0.9(e + p^{us}) - 1.6y)_{t-1} - 0.13\Delta e_{t-1} + Seas & \text{(21c)} \end{cases} \tag{21}$$

For this period there is not a valid error-correction model for the exchange rate in spite of the fact that the long-run relationships still hold. Contrast this situation with that of the 1945-1981 period where there were three error-correction models for it. There is one equation for the rate of inflation but this time it comes from the PPP condition and not from the money demand. This means that inflation now can be forecast conditioned on the exchange rate but not on the monetary aggregate. The Mexican case during the eighties has been a common reference for studies of pass-through.

During the previous period, there was not a valid error-correction model for nominal money, but for the 1983-2000 sample there are three of them. The first one comes from the money demand (equation 1); a second model comes from the standard monetary model (5); and the third one from the model that combines domestic monetary fundamentals with the foreign price level. This remarkable switch in the direction of the long-run causality is new in the literature and has a plausible explanation.

7 An Interpretation of the Changes in the Long-Run Relationships and the Dynamics

The changes reported above are striking and probably do not have a single cause. We first discuss the changes in the long-run relationships and then the changes in the dynamics. The study of these changes is important because the failure of the monetary model or PPP is often attributed to "instabilities." The fact that the long-run relationships and the dynamics had changed so noticeably in Mexico without concealing the functioning of the simplest version of the monetary model calls into question this widely-quoted hypothesis (see, for example, Chinn, 1999 and Rapach and Wohar, 2001).

7.1 Changes in the Long-Run Relationships

The strategy of splitting the sample to obtain cointegration relationships and comparing the parameters from each part is not rare in well-known applications. For example, Lucas (1988) and Stock and Watson (1993) studied the money demand for M1 using nearly a century of data and concluded that income elasticity is unitary in the US. However, Ball (2001) split the sample around the end of WWII and showed that by including just seven more years to Stock and Watson's data the hypothesis that the parameters for the two subsamples were equal was rejected using the same statistical methods.[11]

In the case of Mexico, obtaining a long-run money demand for narrow money has not been a trivial matter. For example, Arrau *et al.* (1995) could not find a valid cointegration vector for the demand of M1. They attributed it to financial innovation but this hypothesis is evidently exaggerated because innovation in the financial sector has been regarded, at most, as the reason behind the instability of the short-run money demand in the US and even in this case such an effect has been questioned.[12] Actually, some work has led

[11] He obtained an income elasticity of 0.5 for the 1946-1994 period. This figure was also obtained by Dutkowsky and Cynammon (2002) for the 1959-2000 period.

[12] Ball (2002) shows that if the opportunity cost is measured properly the short-run money demand for M1 in the US is stable.

to obtaining long-run demands for all monetary aggregates in Mexico (see Garces-Diaz, 2003).

Our results show that before 1982, the opportunity cost had no role in the long-run money demand and then it became important after that year. Also, the income elasticity dropped from 1 to 0.5. A likely reason for these changes in the long-run parameters was the passage of the economy into a more inflationary environment. This hypothesis is suggested by the fact that in high inflation economies the opportunity cost parameter becomes higher and the scale variable becomes less important.[13]

The change in the mean of the real exchange rate is not a novelty either. Hegwood and Papell (1998) found that in several cases where they proved PPP to be valid, the mean to which the real exchange rate reverted had shifted. Noriega and Medina (2000) applied the same procedure to the Mexican case and found a shift around 1982. Possible explanations for the permanent depreciation in Mexico are a drastic fall in the terms of trade and the debt overhang that followed the 1982 crisis. In any case, these instabilities did not conceal the existence of the long-run relationships that have been so hard to prove in many other countries.

7.2 Changes in the Adjustment Dynamics

The changes in the short-run behavior are more intriguing. They remain valid even if we impose the same set of long-run parameters for both subsamples. They help in the understanding of two of the most important empirical issues of monetary economics: the forecastability of the exchange rate and the frequent lack of statistical causality from money to prices. We argue that these changes are implied by forward-looking behavior of economic agents in the face of some drastic events.

[13]Two examples where the scale variable has no role are the Cagan (1956) money demand for the German hyperinflation episode and the Kamin and Ericsson (1993) money demand for Argentina.

7.2.1 Forecastability of the Nominal Exchange Rate

Many economists have spent a lot of time trying to find a method to forecast the nominal exchange rate.[14] So far, these efforts have not reached their goal.[15] It is unclear why the nominal exchange rate, being an asset price, should be forecastable even if the right fundamentals are identified. The price of an asset could be systematically predicted with more accuracy than that implied by a random walk only if the market is inefficient. In the case of the exchange rate, such inefficiencies are possible and central banks usually bear the costs. That is what was happening in Mexico previous to 1982.

A famous episode of devaluation occurred in Mexico during the seventies. The peso had been in fixed parity since 1954 but the market apparently was expecting an adjustment after 1972, when both the public deficit and the money supply went up sharply. The devaluation took longer than expected and the concept of "peso problem" was born.[16] During that time the market looked inefficient because the monetary fundamentals were not consistent with the exchange rate. That situation lasted only until the Mexican Central Bank ran out of reserves and the devaluation finally took place at the end of 1976. The first devaluations of 1982 were also caused by an expansion of the public deficit and the money supply. The sequence of events makes possible to represent the adjustment process of the nominal exchange rate with an error correction mechanism conditional on either relative prices or monetary fundamentals.

When the Mexican Central Bank gave up the policy of a fixed parity in favor of different intermediate regimes, such statistical representation for the adjustment mechanism was no longer appropriate. The exchange rate became weakly exogenous with respect to both the price level and nominal money. Other studies about the monetary model have included situations where there was a move from fixed parity to a free-floating exchange rate (Chinn, 1999 and Rapach and Wohar, 2001). They assume that the dynamics remained constant after

[14] For example: "Our results not only lend support to economists' beliefs that the exchange rate is inherently predictable..." (Killian and Taylor, 2001).

[15] See Neely and Sarno (2002) for a review on the issue.

[16] This expression is usually attributed to Milton Friedman.

the change of policy, but that idea might compatible with an efficient market in some cases. The change in the direction of the long-run causality seems necessary if the market reaches some level of efficiency. To see this consider the following.

According to a widely-accepted theory, the price of a stock is determined by the present value of the stream of dividends; if the price and the dividends are nonstationary variables then the present value theory suggest they should be cointegrated. Dividends are the economic cause of the price of a stock but that does not translates into statistical causality in the same direction. Actually, it should be the case that stock prices Granger-cause dividends through the 'spread' or long-run equilibrium error. In fact, Campbell and Shiller (1987) use the 'spread' and the change of the dividends to perform their test of the present value model. Although, in principle, a cointegration relationship does not impose the direction of (statistical) causality, in the case of stock prices and dividends we should expect to see the former Granger-causing the latter.

A similar argument can be made about the nominal exchange rate. This variable is the result of the present value of future realizations of monetary fundamentals. If the market is efficient, the direction of Granger causality through the 'spread,' or equilibrium error, should run from the exchange rate to monetary fundamentals or to relative prices, which are more closely related to monetary fundamentals than the exchange rate.[17]

Because of this, the abandonment of the "inefficient" exchange rate regime followed by the Mexican Central Bank until 1981 should cause a switch of direction in the long-run causality (weak exogeneity) properties among the variables. This switch probably occurred after the end of Breton Woods in the cases studied by Rapach and Wohar (2001) and it should explain why the evidence of forecastability of the nominal exchange rate even in those cases is not "beyond reasonable doubt" (Neely and Sarno, 2002). However, this last point is left for future research.

[17]Frenkel (1978), in his study of the floating period of the 20's, found that the direction of causality ran from prices to the exchange rates so he estimated "price equations."

The fact that no error correction mechanism exists for the nominal exchange rate during the 1983-2000 period does not mean that knowledge of the monetary fundamentals is of no use for the market. Rather, it means that it would be very strange that with such a tool and cheap information one could be systematically forecasting the level of an asset price. The market must incorporate the information contained in the fundamentals but by the time the econometrician gets the data, the nominal exchange rate has already incorporated it.

7.2.2 The Role of Money in Models of Inflation

The other dynamic aspect to be discussed is the switch in the direction of causality between money and prices. This relationship has always been controversial. For example, Hendry and Ericsson (1991) pointed out that the money demand for the UK in Friedman and Schwartz (1982) was misspecified and, more importantly, noninvertible even after obtaining a correct alternative. That result is the basis of the claim, also found in Hendry (1999 and 2001), that money is not the only determinant of inflation over the long run. However, Friedman and Schwartz (1991) rejected the notion that their result was based on a single money demand equation and that their aim was "to explain movements longer than a business cycle and to abstract from strictly intracyclical effects...we limit out attention to secular effects, while they [Hendry and Ericsson] seek a single econometric specification that simultaneously describes cyclical and secular movements."

In short, the case presented by Friedman and Schwartz was based on long-run relationships among the variables while the main contribution of Hendry and Ericsson was to provide an error-correction model that could account for the dynamics of the money demand. That error-correction model implied that prices and no money was the weakly exogenous variable in the adjustment process.

Similar findings are common in several countries. This paper gives another perspective on this issue because it shows that the long run relationships hold for the whole sample and that the direction of the long-run causality between prices and money switched in 1982. This implies that in the long run the nature of inflation is the same regardless of the direction of causality. One can formulate an argument similar to the one used for the exchange rate and monetary fundamentals to justify the switch in the long-run causality.

Until 1981, the Mexican Central Bank issued money to finance the public deficit. This process began to accelerate in 1972 and it provoked a quick rise of inflation and, eventually, a devaluation of the peso in 1976. This sequence of events makes that in statistical models of inflation for that period money appears as the most important variable. On the contrary, from 1983 to 2000 that role has been performed by the nominal exchange rate and no monetary aggregate is a significant variable in well-specified statistical models of inflation. However, this switch might be also a reflection of the forward-looking behavior of economic agents if during the period 1983-2000 the public was adjusting the prices before any monetary expansion took place. This hypothesis would conciliate the monetary nature of inflation with the lack of explanatory power of money for the 1983-2000 period. It is rather common that financial variables appear as exogenous in statistical tests as a consequence of forward-looking behavior. It is possible that the same can be observed in the case of the relationship between prices and money as price setters foresee the behavior of the monetary authority.

8 Conclusions

This paper analyzes the changes in the long-run relationships and dynamics for money, prices and the exchange rate in Mexico from 1945 until 2000. The Mexican case resembles a monetary “natural experiment” for the following reasons: first, several basic theoretical propositions, that are difficult to prove in most countries, hold simultaneously for the whole period and for nonoverlapping subsamples; second, some striking changes in the most important dynamic aspect shed new light on two important issues of monetary economics. One of them is about the possibility of forecasting the nominal exchange rate and the other is about the direction of causality of prices and money.

We demonstrate that PPP and two versions of the monetary model of exchange rate determination hold for the whole 1945-2000 period. The sample is split about 1982 and we show that these relationships can also be obtained for each subsample and even for the short free-floating period, 1995-2000. In all cases, the signs are correct and the magnitudes are reasonable. This is different from the problems that are reported in other studies. The critical characteristic for the success of the model is the high speed of adjustment.

Because of the evidence of a structural break in 1982, the common argument of instabilities to explain the lack of success of the monetary model in most countries is not as compelling as many economist believe. Those instabilities, if they exist, should be investigated and used to explain how they affect the estimation of the model. Not only do we prove that the monetary model holds, we also demonstrate that its building blocks can also be obtained for nonoverlapping subsamples. This is at odds with the belief that they are unlikely to hold at each point of time.

We examined the changes in the weak exogeneity properties that produced a very peculiar set of error-correction models. For the 1945-1981 sample, the long-run causality ran from money to prices to the exchange rate while for the 1983-2000 period the ordering was reversed. The long-run money demand underwent a conspicuous structural change in 1982. This change was probably caused by a shift toward a more inflationary environment after the outbreak of the 1982 debt crisis. Simultaneously, a change in the dynamics of inflation and the exchange occurred.

Before that year, the long-run money demand had a very simple form where the elasticity of income was one and the coefficient for the opportunity cost was zero. Money was a direct cause of inflation because the Central Bank had to finance the public deficit with the emission of money. The nominal exchange rate was adjusted throughout the devaluations that followed periods of increasing inflation. Because of this, the exchange rate is forecastable based on monetary fundamentals or relative prices.

From 1983 to the end of the sample, the long-run demand for money has an income elasticity of less than one (0.5) and a negative value for the interest rate semi-elasticity (-0.5). The inflation process also acquired a very different form. The price level is determined by the PPP condition and the inflation dynamics by the error-correction mechanism associated with this long-run relationship. No significant effect is found for either excess money demand or money growth. Differently from what occurred during the 1945-1981 period, the exchange rate cannot be forecast.

The changes in the dynamic properties are consistent with forward-looking behavior. The exchange rate was forecastable only when there was a source of inefficiency. When this inefficiency was removed, the exchange rate could not longer be predicted on the basis of the fundamentals alone. However, the existence of a long-run relationship requires that another variable becomes error-correcting and this explains the switch in the weak exogeneity property. A similar argument can be made for the forecastability of inflation on the basis of money. Until 1981, money was a direct cause of inflation because of the monetization of the public deficit. When this practice was eliminated, that causation was not longer active. However, the long-run relationships required other error correcting variables. The causality was turned around and money became forecastable on the basis of prices or the exchange rate.

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A Data Sources

1. Mexico:

   GDP, Y, E, i, W, P:1980-2002 Instituto Nacional de Estadística, Geofrafía e Informática (INEGI).

   http://www.inegi.gob.mx

   Monetary aggregates and the Wholesale Price Index for Mexico City were taken from Banco de México

   http://www.banxico.org.mx.

   Data for the 1940-1979 period came from "Estadísticas Históricas de México," INEGI.

2. United States:

   CPI (P) was taken from Department of Labor Bureau of Labor Statistics site:

   ftp://ftp.bls.gov/pub/special.requests/cpi/cpiai.txt.

   Monetary aggregates $M1$ y $M2$ were obtained from:

   http://research.stlouisfed.org/fred/data/monetary.html

   Money series before 1959 was taken from Bordo et al. (1998).

   US GDP was taken from:

   http://www.bea.doc.gov/bea/dn/gdplev.xls.

B Figures and Tables

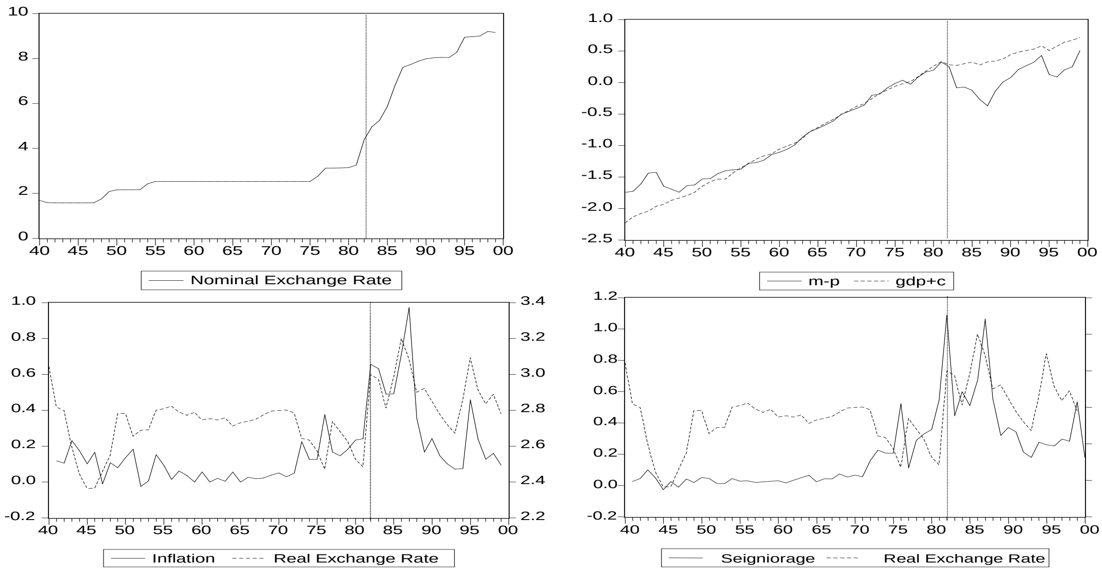

Figure 1: The Relationship Among the Exchange Rate, Money and Prices.

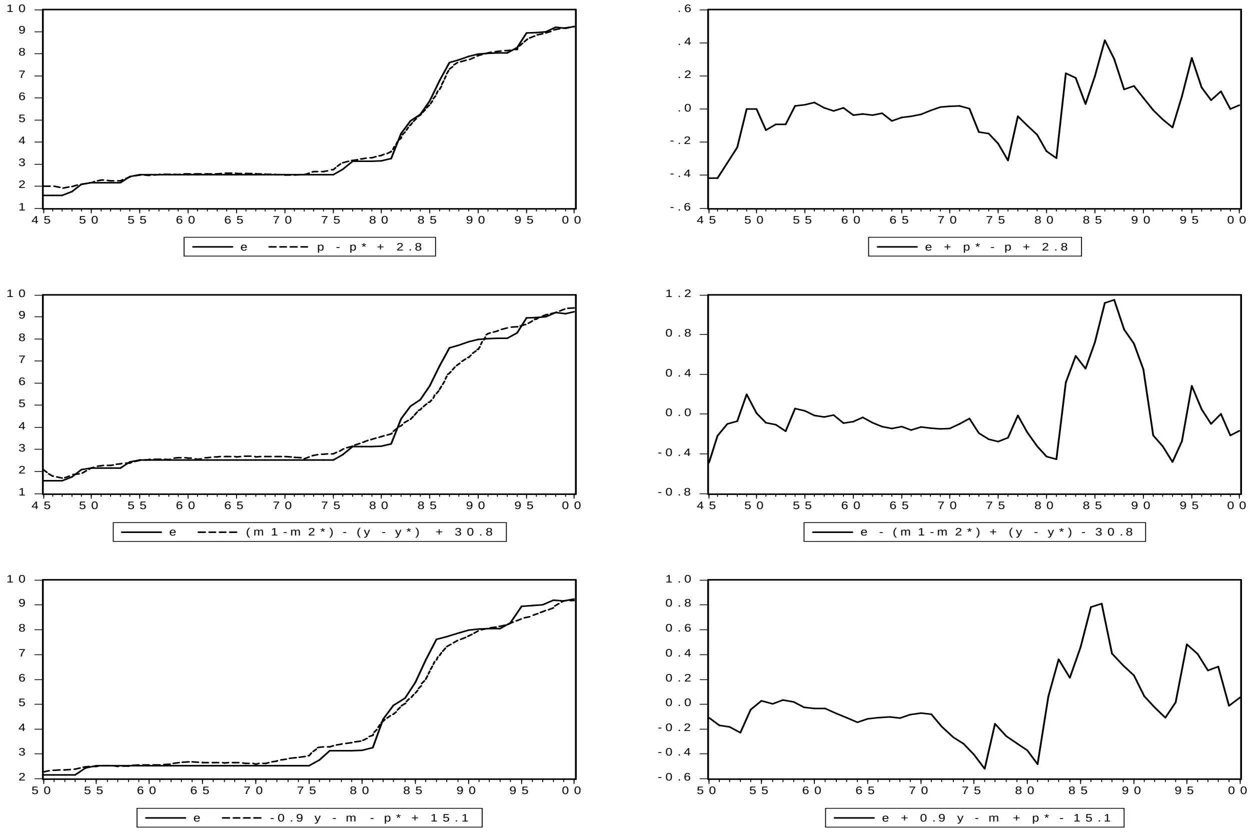

Figure 2: Relaciones de Largo Plazo del Tipo de Cambio Con Tres Conjuntos de Fundamentales.

Table 1: Augmented Dickey-Fuller Unit Roots Test

Variables (In Logs)	Annual(1945-2000)			Quarterly (1980-2000)		
Levels						
	Specification	Lags	Statistic	Specification	Lags	Statistic
Currency (m)	T,C	1	-1.71	C	4	-2.19
Price Level (p)	T,C	1	-1.61	T,C	4	-1.35
Real Balances $(m-p)$	T,C	1	-2.24	T,C	4	-2.99
GDP (gdp)	C	0	-2.49	T,C	4	-2.47
Index of Industrial Production (y)			.	T,C	4	-2.92
Nominal Exchange Rate (e)	N	1	1.67	T,C	2	-1.34
US Price Level (p^{us})	N	1	2.89	N	4	2.74
Real Exchange Rate $(e+p^{us}-p)$	C	0	-3.22[b]	T,C	4	-3.72[b]
Nominal Wages (w)			.	T,C	4	-2.34
Nominal Interes Rate (i)			.	N	2	-0.89
Differences						
Currency (m)	C	0	-3.23[b]	N	4	-1.25
Price Level (p)	C	0	-2.93[b]	T,C	0	-3.27[c]
Real Balances $(m-p)$	C	0	-6.10[a]	C	4	-3.09[b]
GDP (gdp)	N	1	-1.93[c]	C	3	-3.30[b]
Index of Industrial Production (y)			.	C	3	-3.81[a]
Nominal Exchange Rate (e)	N	0	-3.47[a]	C	1	-3.69[a]
US Price Level (p^{us})	N	0	-2.38[b]	N	3	-2.46[b]
Real Exchange Rate $(e+p^{us}-p)$	N	1	-7.63[a]	C	0	-9.94[a]
Nominal Wages (w)			.	T,C	2	-14.12[a]
Nominal Interes Rate (i)			.	N	2	-8.44[a]

[a] 1% significance

[b] 5% significance

[c] 10% significance

In the specification column C, T and N stand for constant, trend and nothing.

Table 2: Descriptive Statistics of the Main Variables (Annual Data)

Variables	1945-2000		1945-1981		1983-2000	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Rate of Growth of Currency (Δm)	0.21	0.17	0.14	0.10	0.33	0.20
Rate of Growth of Real Output (Δgdp)	0.05	0.03	0.06	0.02	0.03	0.04
Domestic Inflation (Δp)	0.17	0.20	0.09	0.09	0.31	0.26
Depreciation Plus US Inflation $\Delta(e + p^{us})$	0.18	0.25	0.09	0.10	0.30	0.31
Real Exchange Rate ($e + p^{us} - p$)	2.76	0.16	2.69	0.13	2.89	0.14