

# IMF Working Paper

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## Real Exchange Rate Response to Capital Flows in Mexico: An Empirical Analysis

*Marcelo Dabós and V. Hugo Juan-Ramón*

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**Real Exchange Rate Response to Capital Flows in Mexico: An Empirical Analysis**

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**Abstract**

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This study shows that in Mexico there is a long-run relationship between the real exchange rate and capital inflows, the external terms of trade, and productivity in the manufacturing sector. A once-and-for-all unit increase in the ratio of quarterly capital inflow to quarterly (annualized) GDP causes a long-run real appreciation of the peso of about 12 percent. The analysis also reveals a structural break in 1995, which coincides with the change to a floating exchange rate arrangement, and an overvaluation of the peso in real terms on the eve of the end-1994 crisis in the range of 12 to 25 percent.

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## I. INTRODUCTION AND MOTIVATION

Mexico had relatively stable capital inflows until the early 1980s when it started experiencing large capital movements (Figure 1b). The massive capital outflows that resulted from the debt crisis of 1982 began to subside in early 1984 and were replaced by inflows after 1988 in response to the implementation of a stabilization program, privatization, and structural reforms in the mid-1980s. The inflows intensified following the Brady debt reduction agreement in early 1990. Again, capital flowed out during the 1994-95 crisis, but flowed back in 1997 as a result of successful stabilization measures and further structural reforms.

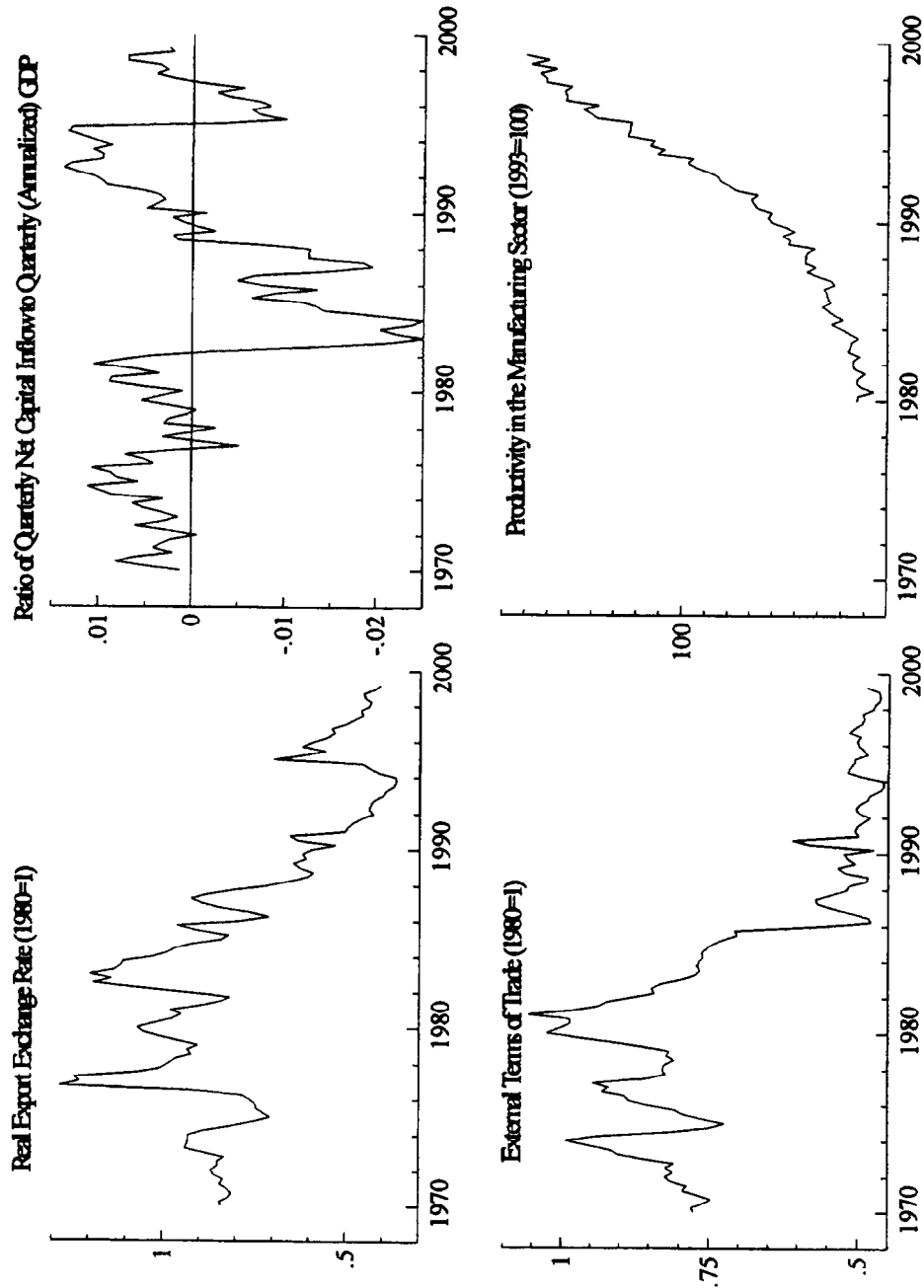
In most emerging economies, large capital inflows followed by sudden reversals (triggered by adverse shocks) have caused fluctuations in the real exchange rate. This paper examines the long-run response of the real exchange rate to capital flows, the external terms of trade, and productivity in the manufacturing sector in Mexico during 1982:1-98:4. It also studies the short-run dynamic properties of those variables. The paper addresses neither the causes of capital movements, its composition, nor its consequences across countries or regions, which have been dealt elsewhere in the literature (see Calvo, Leiderman, and Reinhart, 1993b, and Khan and Reinhart, 1995).

The post-crisis resumption of capital inflows in Mexico has caused a market-driven real appreciation of the peso, raising concerns about Mexico's external competitiveness (Figures 1a). One of the motivations for this paper arose from the suspicion, shared by some public sector Mexican economists, that post-crisis capital inflows have caused real appreciations larger than in the past. To cope with the "unsolvable problem" of real appreciations owing to capital inflows, various strategies have been suggested, such as implementing a loose monetary policy to induce nominal and real depreciations, adopting a wide crawling band for the nominal exchange rate, introducing capital controls,<sup>2</sup> tightening the fiscal position, strengthening the financial system, deepening structural reforms, cutting red tape to reduce the "costs of doing business," and further opening the external current account.

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<sup>2</sup>The crisis in Asia triggered a renewed interest in the question of whether capital controls may help reduce the risk of external imbalances and financial crises. At the 1998 World Economic Forum, the IMF First Deputy Managing Director, said that "For countries that can make them work, capital controls could be acceptable to the IMF for a transitional phase until the financial system of a country is sufficiently strong to deal with surges in short-term loans from abroad."

Figure 1  
Selected Macroeconomic Variables for the Period 1970:1-99:2



The consequences of opening up an economy were studied by Khan and Zahler (1983), who provide a thorough and systematic analysis of the short-run effects of liberalization on both the current and capital accounts, as well as an analysis of the optimal sequencing. Sjaastad and Manzur (1996), who analyze the effect that the degree of openness has on the response of the real exchange rate to capital flows, revisited some of these issues. They assert that the real exchange rate reacts more strongly to capital flows in highly protected economies than in those with more liberal commercial policies, because protection reduces not only the volume of trade but also the margins of substitution between tradable and nontradable goods.<sup>3</sup> To examine whether this hypothesis holds true for Mexico was another motivation of this paper. The paper's main findings are:

(i) There is a long-run relationship between the real exchange rate (defined as the relative price of either exports to consumer price, or tradables to nontradables) and a few explanatory variables: the ratio of capital inflows to GDP, the external terms of trade, and productivity in the manufacturing sector. These variables are statistically significant, have the expected sign, and there is indication of a structural break in 1995. This simple model explains fairly well variations in the real exchange rate in spite of leaving out the ratio of public spending in tradables to nontradables goods and services (owing to a lack of reliable data) from the set of explanatory variables.

(ii) We estimated a static and a dynamic model of the real exchange rate. The former follows the Engle-Granger (1987), methodology and the latter the Hendry (1995) methodology based on an equilibrium-correction representation of the autoregressive-distributed-lag model. The dynamic estimation confirms results obtained from the static model: the existence of a long-run relationship between the real exchange rate and the explanatory variables, the sign and order of magnitude of all coefficients, and the structural break in 1995. Furthermore, the dynamic estimation suggests that disequilibria are corrected relatively fast: 40 percent of a disequilibrium in the real exchange rate originating in a given quarter is corrected in the following quarter.

(iii) For the sample period of 1982:1–98:4, the long-run relation extracted from the dynamic estimation indicates that a once and for all unit increase in the ratio of quarterly capital inflow to quarterly (annualized) GDP would, other things equal, lead to a long-run real appreciation of the peso (defined by the relative price of exports to consumer price) of about 12 percent.

(iv) The results suggest that Mexico's real exchange rate was overvalued on the eve of the end-1994 crisis in the range of 12 to 25 percent. However, after overshooting in the first quarter of 1995, the real exchange rate reverted to equilibrium by the end of 1995.

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<sup>3</sup>The authors found empirical support for their hypothesis in the cases they studied: a closed economy (Argentina in 1979:1–92:4), a semi-open economy (Australia in 1977:3–94:3), and an open economy (Canada in 1971:1–94:3). They measure the degree of openness by the ratio of exports plus imports to GDP, and report that for the period of 1978–90, this ratio was 15 percent for Argentina, 34 percent for Australia and 52 percent for Canada.

(v) The analysis reveals a structural break in 1995. Recursive estimations show that all coefficients were fairly stable until 1995, when they jumped to a new plateau and remained stable thereafter. Interestingly, after 1995, the real exchange rate is more responsive to movements in the ratio of capital inflows to GDP: a once-and-for-all-increase in the ratio of quarterly capital inflow to quarterly (annualized) GDP by one unit, other things equal, would have led to a long-run real appreciation of the peso of about 9 percent before 1995, and of about 12 percent after 1995. We do not have a thorough explanation for the structural break; however, it coincides with the change to a floating exchange rate arrangement.

(vi) We could not confirm the Sjaastad and Manzur hypothesis that the real exchange rate reacts less strongly to capital inflows in relatively open economies than in relatively closed economies. The greater openness of the Mexican current account since mid-1980s seemed not to have affected the magnitude of the real exchange rate's response to capital inflows. It is difficult, however, to identify the effect of trade liberalization on the exchange rate response to capital flows as many other structural reforms were implemented by the same time.

## II. VARIABLE SOURCE AND DEFINITIONS, AND METHODOLOGY

The source of all the data is the Bank of Mexico. The data consist of quarterly observations, for the period 1970:1-98:4, for the natural logarithm of the relative price of exports to consumer price (i.e., the export real exchange rate), RERX; the natural logarithm of the relative price of imports to consumer price (i.e., the import real exchange rate), RERM; the ratio of quarterly net capital inflows to quarterly (annualized) gross domestic product,  $k_y$ ; the natural logarithm of the external terms of trade, ETT; and, for the period 1982:1-98:4, the natural logarithm of an index of productivity in the manufacturing sector, PRO. (Figure 1 plots these variables, except for RERM). Net capital inflow (denoted by  $k$ ) is defined as the peso value of imports of goods and nonfactor services minus the peso value of exports of goods and nonfactor services, and the productivity index is the ratio of the index of volume of production in the manufacturing sector divided by an index of hour-person worked. The productivity index is a relatively new series constructed by the Bank of Mexico, which is an important determinant of the real exchange rate in Mexico.

Specifically,  $RERX = E + P_X - CPI$ ;  $RERM = E + P_M - CPI$ ;  $ETT = P^*_X - P^*_M$ ; and  $k_y = k/GDP = e(m p^*_M - x p^*_X)/GDP$ . Except for GDP, variables in upper case represent the logarithm of those in lower case. Thus,  $e$  denotes the nominal exchange rate defined as Mex\$ per US\$,  $p^*_X$  ( $p^*_M$ ) stands for the dollar price index of exports (imports) of goods and nonfactor services,  $x$  ( $m$ ) is the volume of exports (imports) of goods and nonfactor services, and net capital inflow in terms of US dollar equals  $m p^*_M - x p^*_X$ .

### A. Derivation of the Equation to be Estimated

The theoretical relationship between the logarithm of the true real exchange rate, TRER, and  $k_y$  and PRO (derived in the appendix) is:

$$TRER = \text{constant} + \Theta_y k_y - \lambda PRO \quad (1)$$



where, TRER is defined as the logarithm of the relative price of tradable and nontradable goods ( $P_T - P_H$ ),  $\Theta_y$  is the long-run response of the true real exchange rate to changes in the ratio of capital inflow to GDP, and  $\lambda$  is the long-run response of the true real exchange rate to changes in productivity. The true real exchange rate is difficult to construct because it requires estimating the price index of tradables and nontradables (the current series are not reliable and are under revision by the Bank of Mexico). Thus, to estimate the key parameter  $\Theta_y$  while avoiding the construction of TRER, we recast equation 1 into equation 2.

As an intermediate step, we define the "real exchange rate" (in logarithm) as  $RER \equiv P_T - P$ , where  $P_T$  is the domestic price index of tradable defined as a weighted average of the domestic price indices of imports and exports using true weights:  $P_T = \omega P_M + (1-\omega) P_X$ ,<sup>4</sup> and  $P$  is the consumer price index defined as a weighted average of nontradable and tradable goods:  $P = w_H P_H + (1 - w_H) P_T$ . Plugging the definition of  $P$  in that of  $RER$ , yields  $RER = P_T - (w_H P_H + (1 - w_H) P_T) = w_H (P_T - P_H) = w_H TRER$ . Thus,  $TRER = (1 / w_H) RER$ . And using this expression in equation 1, obtains:

$$RER = w_H \text{ constant} + w_H \Theta_y k_y - w_H \lambda PRO \quad (1a)$$

As  $RER$  still involves the price index of tradables (which includes the unknown weights), a further transformation is needed. Plugging the definition of  $P_T$  in that of  $RER$ , yields:

$$RER = P_T - P = \omega P_M + (1 - \omega) P_X - P = (P_X - P) - \omega (P_X - P_M) \quad (1b)$$

Defining the logarithm of the "exports real exchange rate" as  $RERX = P_X - P$ , and the logarithm of the domestic terms of trade as  $TT = P_X - P_M$ , we have:

$$RER = RERX - \omega TT \quad (1c)$$

and using (1c) to eliminate  $RER$  from (1a), yields:

$$RERX = w_H \text{ constant} + w_H \Theta_y k_y + \omega TT + w_H \lambda PRO \quad (1d)$$

The relation between the domestic and external terms of trade is given by:

$$p_X / p_M = [e_X (1+s_X) / e_M (1+t_M)] (p^*_X / p^*_M)$$

where  $s_X$  is the average rate of subsidies on exports,  $t_M$  is the average rate of tariffs on imports (including equivalent tariffs from quantitative restrictions to imports), and  $e_X$  ( $e_M$ ) is the nominal exchange rate that applies to exports (imports). In logarithm form:

$$TT = a + ETT \quad (1e)$$

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<sup>4</sup>For a derivation and analysis of the true weights, see Sjaastad (1980).

where  $a$ , the commercial policy parameter, is the logarithm of  $[e_X (1+s_X) / e_M (1+t_M)]$  and  $ETT = P^*_X - P^*_M$  is the logarithm of the external terms of trade. Using (1e) to eliminate  $TT$  from (1d) and assuming that commercial policy does not change, obtains:

$$RERX = (w_H \text{ constant} + a \omega) + w_H \Theta_y k_y + \omega ETT - w_H \lambda PRO \quad (1f)$$

Redefining all parameters in equation 1f and introducing a stochastic term,  $u$ , yield the equation to be estimated:

$$RERX(t) = \beta_0 + \beta_1 k_y(t) + \beta_2 ETT(t) + \beta_3 PRO(t) + u(t) \quad (2)$$

Note that we cannot estimate the response of the true real exchange rate to capital inflows as a percentage of GDP, i.e.,  $\Theta_y$ , directly from equation 2; however,  $\Theta_y$  can be derived by dividing the estimated parameter  $\beta_2$  by the share of nontradables in the consumer price index.

As equations (1b) and (1c) also can be expressed as  $RER = (P_M - P) - (1 - \omega)(P_X - P_M) \equiv RERM - (1 - \omega) TT$ , equation 2 also can be estimated using the import real exchange rate,  $RERM$ , as the dependent variable:

$$RERM(t) = \beta_0 + \beta_1 k_y(t) + (1 - \beta_2) ETT(t) + \beta_3 PRO(t) + u(t) \quad (2')$$

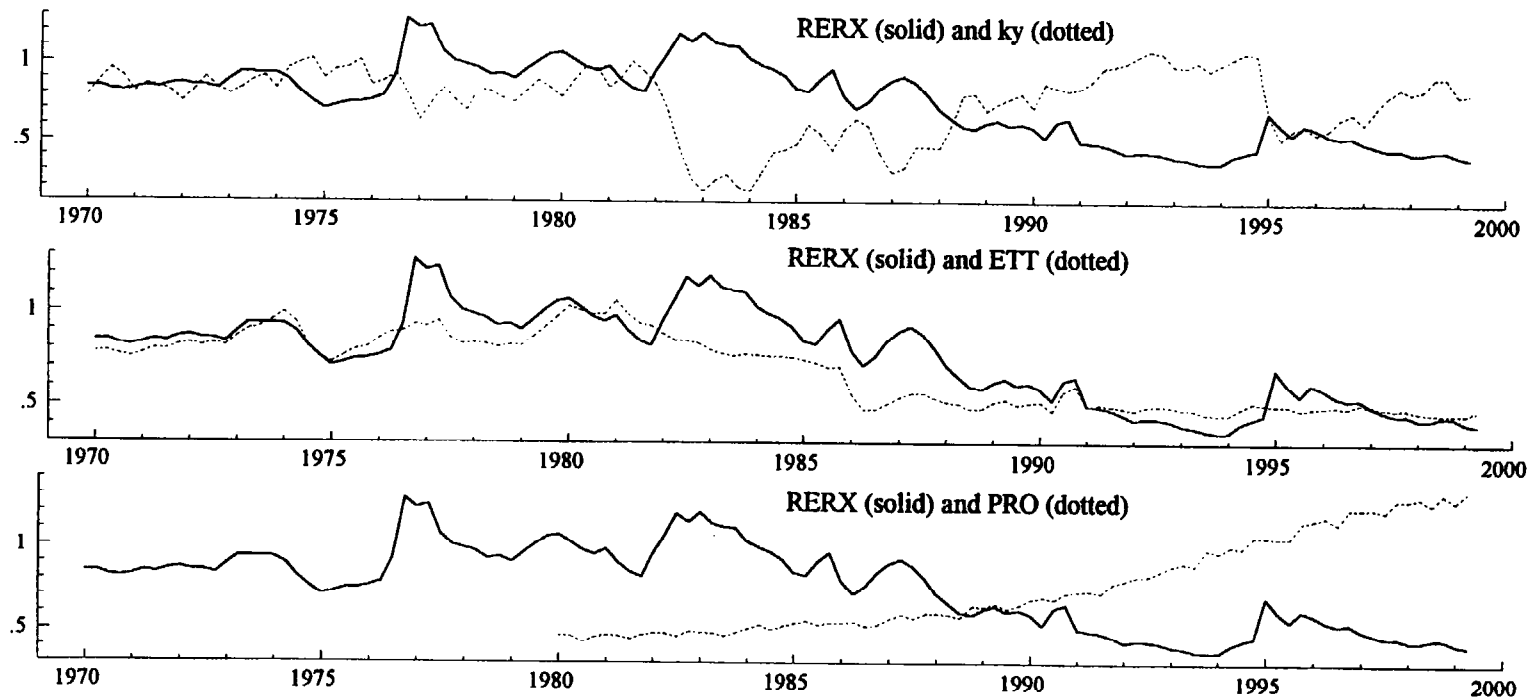
## B. Methodology

We estimated equation 2 in the context of static and dynamic models. In a static setting, we test for the existence of a long-run relationship among the variables in equation 2 using the Engle-Granger (1987) methodology. We also examined the stability of coefficients over time. In a dynamic setting, we verify the existence of a long-run relationship among the variables in equation 2, the sign, magnitude, and constancy of coefficients, and the dynamic properties of equation 2 using an equilibrium-correction single-equation model proposed by Hendry (1995).

## III. AN OVERVIEW OF THE DATA

After adjusting all variables in equation 2 to match their means and ranges, we plot the following pairs of variables:  $RERX$  and  $k_y$  (Figure 2a),  $RERX$  and  $ETT$  (Figure 2b), and  $RERX$  and  $PRO$  (Figure 2c). Figure 2 points at the strong correlation between  $RERX$  and each of the explanatory variables: (a) an increase (decrease) in capital inflows as percentage of GDP is closely correlated with a real appreciation (depreciation) of the peso as measured by the logarithm of the export real exchange rate, particularly after the mid-1970s, (b) the logarithm of the export real exchange rate moves in tandem with the logarithm of the

**Figure 2**  
**Range and Mean Match of Key Variables for the Period 1970:1-99:2**



**RERX** : Natural logarithm of the real exchange rate index relevant to the export sector.

**ky** : Ratio of quarterly net capital inflow to quarterly (annualized) GDP

**ETT** : Natural logarithm of the external terms of trade index

**PRO** : Natural logarithm of the productivity index in the manufacturing sector

external terms of trade, and (c) since the early 1980s, the upward trend in the logarithm of productivity in the Mexican manufacturing sector has been associated with a downward trend in the logarithm of the export real exchange rate.

#### IV. ESTIMATION RESULTS

##### A. Estimated Long-Run Relationship in a Static Model

Using the Augmented Dickey-Fuller (ADF) test with five lags, we test first the order of integration of RERX, RERM,  $k_y$ , ETT during 1970:1–98:4 and 1982:1–98:4, and of PRO during the latter period (for which data are available). The ADF tests reveal that those variables are integrated of order one,  $I(1)$ , in both periods (Tables 4 and 5, Appendix II). After establishing that all variables involved are  $I(1)$ , we test whether equation 2 represents a long-run relationship (cointegration) by running an OLS regression of equation 2 (Table 1) and testing the order of integration of the regression's residuals. If the estimated regression's residuals (interpreted as deviations of the RERX from its long-run equilibrium) were integrated of order zero,  $I(0)$ , the variables in equation 2 are cointegrated.

Table 1. Regression Estimates of Equation 2

LHS Variable	RHS Variables and Summary Statistics						
RERX	Const.	$k_y$	ETT	PRO	Adj $R^2$	DW	Sigma
Estimation period:							
1970:1–98:4	0.10 (6.2)	-15.7 (-16.0)	1.02 (29.9)		0.91	0.54	0.099
1982:1–98:4	1.54 (6.7)	-16.2 (-13.1)	0.57 (7.1)	-0.39 (-6.8)	0.95	0.69	0.083

Table 2. Augmented Dickey-Fuller Test on the Levels of the Estimated Residuals of Regressions in Table 1

Estimated Residual of Equation 2:	Test Vale	1 % Critical Value	5 % Critical Value	Decision
Estimation period:				
1970:1–98:4	-3.25	-3.49	-2.89	$I(0)$ at 5 %
1982:1–98:4	-3.35	-3.54	-2.91	$I(0)$ at 5 %

As the estimated residuals are  $I(0)$  at 5 percent significance level (Table 2), the variables in equation 2 exhibit a long-run relationship.<sup>5</sup>

In deriving equation 2, we assumed that the effect of commercial policy on the domestic terms of trade—parameter  $\alpha$  in equations 1e and 1f—is constant. However, the Mexican economy was indeed more open after 1984 (see Tables 8 and 9, Appendix IV) so we included as a regressor in equation 2 a proxy for the degree of openness, which was obtained as a moving average (with a lag of 10 quarters) of the logarithm of the ratio of exports (including net maquila exports) and imports to GDP. For the period 1982:1–98:4, the degree of openness was not statistically significant in determining the real exchange rate, which was expected given that for most of this period the economy was already open. Thus, in the dynamic estimation of equation 2 that was also done for the period 1982:1–98:4 (owing to the limitation of data on productivity) we assumed that commercial policy was constant.

The low Durbin-Watson (DW) statistic of 0.69 strongly suggests the presence of positive first-order serial correlation. In general, the presence of serial correlation will not affect the unbiasedness or consistency of the OLS regression estimators, but it does affect their efficiency. To cope with this problem, we estimate an equilibrium-correction representation of the autoregressive-distributed-lag model (section IV, D) which, among other features, represents a more general procedure to correct for residual autocorrelation than the standard Cochrane-Orcutt.

The variables in equation 2 explain fairly well movements of the real exchange rate as shown in Figures 3a and 3b, which plots actual and fitted values of RERX for the period 1982:1–98:4, and the corresponding residuals. Figure 3a also shows the peso overvaluation gap (relative to the fundamentals) that started in 1991, it deepened by mid-1992, and shrank during 1994; as well as the overshooting of the real exchange rate that followed the December 1994 devaluation.

Estimation of equation 2' (with RERM as the dependent variable) yields basically the same parameters as estimated by equation 2 (with RERX as the dependent variable) for both periods. Also the residuals for both regressions are  $I(0)$  at 5 percent significance level. As equations 2 and 2' yields identical results, all the empirical analysis will be conducted using equation 2.

## **B. Constancy of Coefficients**

To examine the constancy over time of the estimated coefficients, we plot the recursive estimates of equation 2 for the coefficients of  $k_y$ , ETT and PRO (Figures 4a to 4c). Figure 4 reveals some instability of all coefficients during 1985–87, perhaps due to debt

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<sup>5</sup>We also confirmed that equation 2 represents a cointegrated relationship using the Johansen test. The likelihood ratio test indicates one cointegrating equation (involving the four variables considered) at 5 percent significance level.

crisis and uncertainties associated with the introduction of important structural reforms. More important, Figure 4 also shows a clear structural break in 1995: after being fairly stable over time, all parameters jumped to a new plateau in 1995 and remained stable thereafter. Interestingly, the real exchange rate is more responsive to movements in the ratio of capital inflows to GDP after 1995. We do not have a thorough explanation for the structural break; however, it coincides with the change to a floating exchange rate regime arrangement.

### **C. The Effect of Openness on the Response of RERX to Capital Inflows**

To assess the effect that the degree of openness has on the response of the real exchange rate to capital flows, we estimated equation 2 (excluding PRO due to incomplete data) for various subperiods prior and after the trade liberalization implemented between 1983 and 1987.<sup>6</sup> In addition, we restricted the whole sample period to 1970:1–94:1 to eliminate any influence of the 1995 structural break. In all cases, the estimated response of the real exchange rate to capital inflow as a percentage of GDP for the pre-and post-liberalization subperiods did not support the Sjaastad-Manzur hypothesis that more openness reduces the impact of capital flows on the real exchange rate. In fact, the estimated coefficients indicate that the responsiveness of the real exchange rate to capital inflows as a percentage of GDP either has remained at about the same level, or has increased somewhat during the period of greater openness vis-à-vis the relatively close period.

Given that a corollary of the Sjaastad-Manzur hypothesis predicts that the real exchange rate would exhibit more variability during periods of less openness, we tested the null hypothesis of equality of the variances of the export real exchange rate and the ratio of capital inflow to GDP, across the subperiods of 1970:1–84:1 and 1984:2–98:4. The tests accept the hypothesis of no difference between the variances across subperiods for these two variables at the 5 and 1 percent significance level (Tables 6 and 7, Appendix III). Furthermore, for the period 1970:1–94:1, we estimated a recast equation 2 that was derived by postulating that the absolute value of  $\beta_2$  is an upward-sloping linear function of a proxy for the degree of openness, to then substitute this function for  $\beta_2$  in equation 2. The proxy variable is the moving average (10 quarters lag) of the logarithm of the ratio of exports (including net "maquila") and imports to GDP. This approach also failed to confirm the hypothesis that the more open an economy is, the less responsive the real exchange rate is to capital movements.

Although the data for Mexico do not support the aforementioned thesis, we cannot readily dismiss this thesis. The reason is that together with trade liberalization, Mexico initiated a host of structural reforms in the mid-1980s—including financial liberalization, reforms to the foreign investment and the tax codes, privatization, deregulation of internal

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<sup>6</sup>The first stage of trade liberalization in Mexico started in 1983; however, the bulk of the measures were implemented between July 1985 and December 1987 (Mancera, 1997 and Juan-Ramón, 1992). Means difference test show that the greater degree of openness of the Mexican economy after 1984 is statistically significant (Tables 8 and 9, Appendix IV).

Figure 3  
Actual and Fitted Value of RERX, and Residuals from the  
Estimate of Equation 2 for the Period 1982:1-98:4

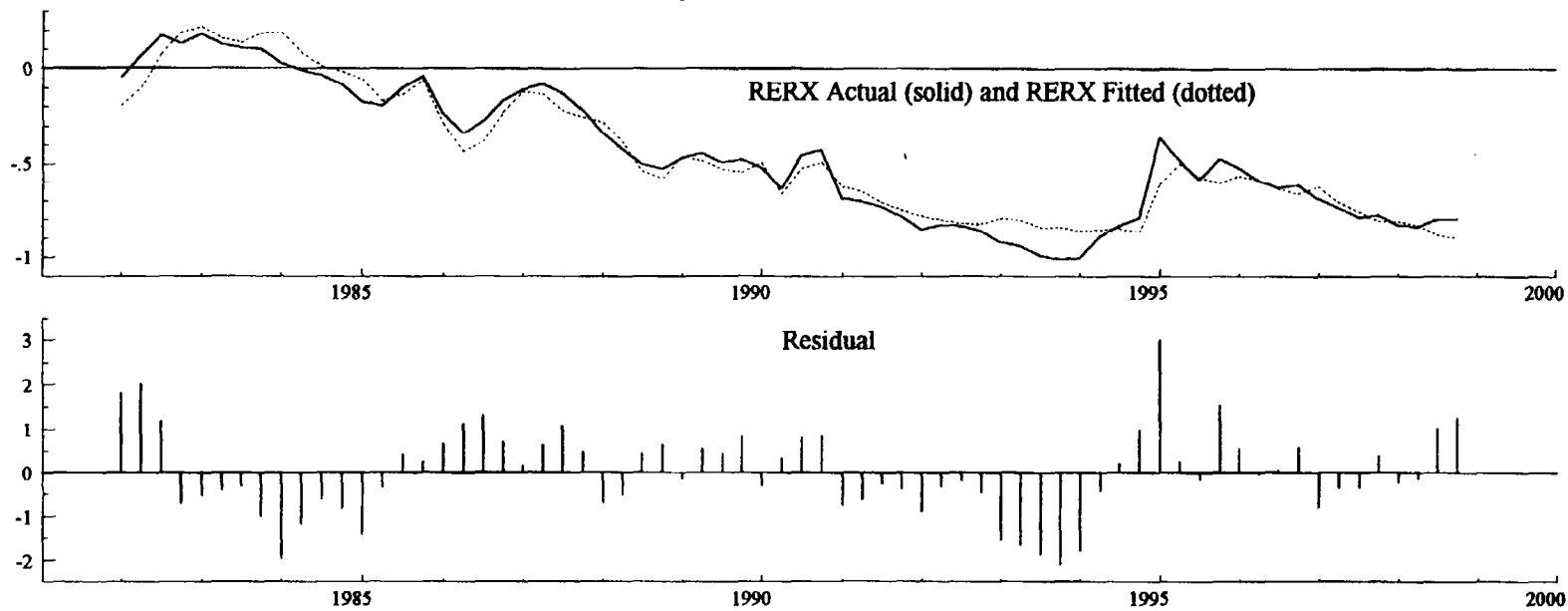
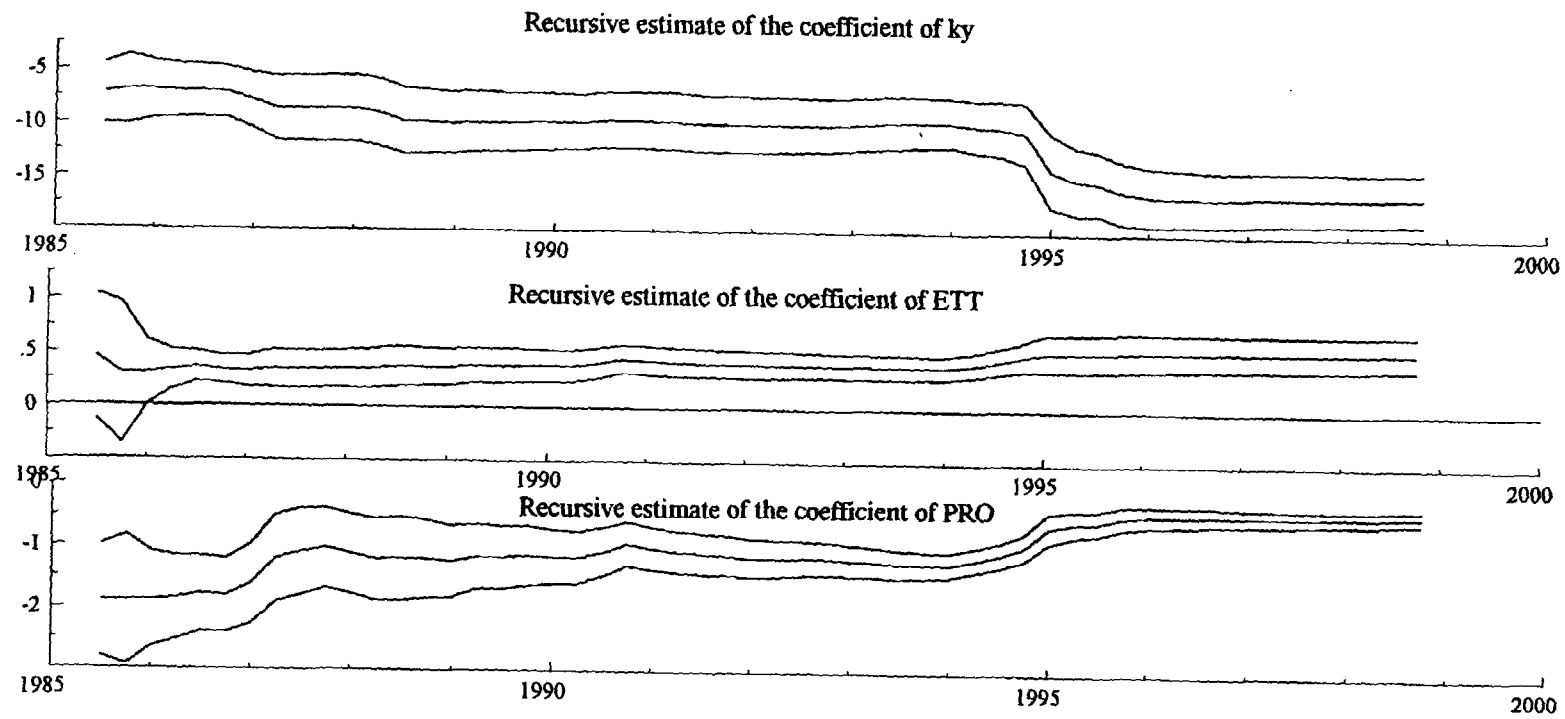


Figure 4  
Recursive estimates of Coefficients of Equation 2 for the Period 1982:1-98:4





trade, and price and exchange rate liberalizations<sup>7</sup>—that could have offset any effect that trade liberalization alone may have on the real exchange responsiveness; thus creating an identification problem in the econometric analysis of the data.

#### **D. A Dynamic Model of the Real Exchange Rate in Mexico: 1982:1–98:4**

##### **1. Equilibrium-Correction Single-Equation Model**

In this section we estimate the parameters of equation 2 following the Hendry (1995) methodology of an equilibrium-correction model (EqCM).<sup>8</sup> Ericsson and Sharma (1998) estimate money demand in Greece in the context of large fluctuations in the inflation rate, introduction of new financial instruments, and liberalization of the financial system applied this methodology. Similarly, in our case the estimation of real exchange model takes place during a period in which there are large fluctuations in capital flows, introduction of structural reforms, and a change in the exchange rate regime.

In our case, the EqCM methodology has the advantage that, in addition to verifying the existence of a long-run relationship, the sign and magnitude of coefficients, and the 1995 structural break found in the static model estimation of equation 2, it also allows us to correct for serial autocorrelation of residuals and to assess the dynamic properties of the export real exchange rate in Mexico. Following Ericsson and Sharma (1996 and 1998), the EqCM representation of equation 2 is derived from an autoregressive distributed-lag model in RERX, ky, ETT and PRO (See the Appendix). The EqCM estimation implies that the first difference of RERX is regressed on the variables listed under RHS variables in Table 3. Thus, the equation to be estimated takes the form:

$$\begin{aligned} \Delta RERX = & \text{Constant} + \text{EqCT} (-1) + ky (-1) + ETT (-1) + PRO (-1) + \sum \Delta RERX (-i) + \Delta ky \\ & + \sum \Delta ky (-i) + \Delta ETT + \sum \Delta ETT (-i) + \Delta PRO + \sum \Delta PRO (-i), \end{aligned}$$

where  $i = 1, \dots, 4$ ; and  $\text{EqCT} (-1) \equiv \text{RERX} (-1) - ky (-1) - ETT (-1) - PRO (-1)$ .

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<sup>7</sup>For example, Mussa (1982) has pointed out that in most countries the purchasing power parity (PPP) real exchange rate has become quite volatile since fixed parities among the major currencies were abandoned in early 1973. It is also argued that the persistent variability in PPP real exchange rate is largely due to inappropriate government policies that influence the allocations of spending in traded and nontraded goods and services.

<sup>8</sup>Although the model estimated here is often called an error correction model, technically speaking it is an equilibrium correction model. Hendry (1995, p. 213) discusses the distinction between the two.

Table 3. Regression Estimate of Equation 2 in the Context of an Equilibrium Error-Correction Representation of the Autoregressive-Distributed-Lag Model

Time period for estimation is 1982:1-98:4

RHS Variables	Coefficient	t-value
Constant	0.56	1.94
EqCT (-1) 1/	-0.41	-2.92
ky (-1)	-5.40	-2.24
ETT (-1)	-0.12	-1.44
PRO (-1)	-0.53	-2.66
$\Delta$ RERX (-1)	0.03	0.19
$\Delta$ RERX (-2)	0.32	1.96
$\Delta$ RERX (-3)	0.44	2.68
$\Delta$ RERX (-4)	0.31	2.06
$\Delta$ ky	-16.01	-5.60
$\Delta$ ky (-1)	10.43	3.18
$\Delta$ ky (-2)	5.38	1.47
$\Delta$ ky (-3)	-0.22	-0.07
$\Delta$ ky (-4)	7.33	3.14
$\Delta$ ETT	0.66	3.92
$\Delta$ ETT (-1)	0.32	1.63
$\Delta$ ETT (-2)	-0.16	-0.79
$\Delta$ ETT (-3)	-0.44	-2.22
$\Delta$ ETT (-4)	-0.17	-0.84
$\Delta$ PRO	-1.16	-2.48
$\Delta$ PRO (-1)	-0.44	-0.80
$\Delta$ PRO (-2)	-0.14	-0.27
$\Delta$ PRO (-3)	-1.14	-2.27
$\Delta$ PRO (-4)	-0.43	-0.89

1/ EqCT(-1) stands for equilibrium correction term, defined as  $RERX(-1) - ky(-1) - ETT(-1) - PRO(-1)$ .  
 $R^2 = 0.78$ ;  $F(23, 47) = 7.1$ ;  $\sigma = 0.05$ ;  $DW = 2.01$ ;  $RSS = 0.13$  for 24 variables and 71 observations.

Both short-and long-run properties can be derived from the estimations shown in Table 3. The coefficient of the equilibrium correction term, EqCT, is significant, confirming that a long-run (cointegrating) relationship exists between the logarithm of the export real exchange rate and the set of explanatory variables. The size of this coefficient implies that adjustment to disequilibria via the equilibrium correction term is relatively quick, as 40 percent of a disequilibrium in a given quarter is corrected in the following quarter. The EqCM appears reasonably well specified judging by the behavior of the fitted and actual values of  $\Delta RERX$ , and the corresponding residuals, which are shown in Figures 5a and 5b, respectively.

## 2. Solving for the steady-state long-run relationship implicit in the estimated EqCM

The steady-state long-run relationship between  $RERX$  and  $ky$ ,  $ETT$ , and  $PRO$  is solved from the estimated EqCM. From Table 3, we have:

$$\Delta RERX = 0.56 - 0.405 \text{ EqCT} (-1) - 5.40 ky (-1) - 0.12 ETT (-1) - 0.53 PRO (-1) + \dots$$

For estimation purposes,  $\text{EqCT} (-1)$  was defined as  $RERX(-1) - ky(-1) - ETT(-1) - PRO(-1)$  (see the Appendix). Introducing this definition in the above equation, yields:

$$\begin{aligned} \Delta RERX = & -0.405 \{ -0.56 / 0.405 + RERX (-1) + (-1 + 5.40 / 0.405) ky (-1) \\ & + (-1 + 0.12 / 0.405) ETT (-1) + (-1 + 0.53 / 0.405) PRO (-1) + \dots \end{aligned}$$

Thus, the emerging long-run relation among  $RERX$ ,  $ky$ ,  $ETT$ , and  $PRO$  is:

$$RERX = 1.4 - 12.3 ky + 0.70 ETT - 0.31 PRO$$

The sign of the estimated coefficients in the long-run relation extracted from the estimated EqCM coincide with those obtained from the estimated equation 2 using the Engle-Granger procedure. The magnitude of the estimated coefficients in the long-run relation extracted from the estimated EqCM are close to those obtained from the estimated equation 2 using Engle-Granger procedure, and are quite similar to those obtained from the estimated equation 2 using Cochrane-Orcutt procedure.<sup>9</sup> The latter is hardly a surprise as the Cochrane-Orcutt procedure is a particular case of a general autoregressive-distributed-lag model, specifically when lagged dependent variables are not considered.

We run again the EqCM but with the equilibrium correction variable,  $\text{EqCT}(-1)$ , defined as  $RERX (-1) - 1.4 + 12.3 ky (-1) - 0.70 ETT (-1) + 0.31 PRO (-1)$ . As expected, the estimated parameter for  $\text{EqCT} (-1)$  is identical to that reported in Table 3; however, and also as expected, the estimated parameters for  $ky (-1)$ ,  $ETT (-1)$ , and  $PRO (-1)$  are all zero.

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<sup>9</sup> The Cochrane-Orcutt estimation of equation 2, not reported in the text, yields:  
 $RERX = 1.8 - 11.3 ky + 0.78 ETT - 0.40 PRO$ .

To assess the relative importance of each explanatory variable, we also run the equilibrium-correction model removing one explanatory variable at the time, and of course, taking this into account in the definition of the equilibrium correction term, EqCT. Capital inflow as a percentage of GDP seems to be the most important variable in the sense that when this variable is removed from the model, the goodness of fit statistics worsen more than the cases in which any other explanatory variable is removed.

### **3. Interpretation of estimated coefficients**

The estimated coefficient of  $k_y$  (-12), which has the expected sign, indicates that a once-and-for-all unit increase in the ratio of quarterly net capital inflow to quarterly (annualized) GDP will cause a long-run real appreciation of the peso of about 12 percent when measured by the export real exchange rate, or about 24 percent when measured by the true real exchange rate. The latter assumes that the share of home goods in the consumer price index is about 50 percent. The estimated coefficient of PRO (-0.31), implies that a one percent increase in the productivity index of the manufacturing sector leads to a long-run real appreciation of the peso of 0.31 percent.

As the long-run elasticity of the export real exchange rate with respect to the external terms of trade is 0.70, an improvement in the external terms of trade leads to a real depreciation of the peso. In general, the sign of this elasticity depends on the magnitude of the income effect in the demand for nontradables (Khan and Montiel, 1987). For example, in the context of a small income effect on the demand for nontradables, an improvement of the external terms of trade (originated in an increase in the dollar price of exportable) would increase the consumer price index by less than proportional to the increase in the export price, i.e., a real depreciation. The analysis for the case in which the improvement in the external terms of trade is brought about by a reduction in the dollar price of importable is similar. The data for Mexico show that throughout the sample period improvements in the external terms of trade led to real depreciations of the peso.

### **4. Constancy of coefficients**

Graphical analysis of parameter constancy in the context of the EqCM confirms the occurrence of a structural break in 1995 as shown in Figures 6a to 6d. Those figures plot the recursively estimated coefficients, and plus-or-minus twice their recursive estimated standard errors, of the variables EqCT(t-1),  $k_y(t-1)$ , ETT(t-1), and PRO(t-1), which are used to estimate the underlying steady-state long-run relationship.

We also estimated the dynamic model for the period of 1982:1-94:4 to quantify the effect of the structural break on the real exchange rate response to quarterly capital inflows as a percentage of quarterly (annualized) GDP,  $k_y$ . The long-run relationship that emerged from this estimation gives an estimated parameter for  $k_y$  of -9.4, as compared with -12.3 for the whole sample period. Thus, the real exchange rate became more responsive to capital inflows after 1995. A once and for all increase in  $k_y$  by one unit, other things equal, would have led

to a long-run real appreciation of the peso (defined by the relative price of exports to consumer price) of about 9 percent before 1995, and of about 12 percent after 1995. We do not have a thorough explanation for the structural break; however, it coincides with the change to a floating exchange rate arrangement.

#### **5. Extent of the peso overvaluation on the eve of the end-1994 crisis**

The next step is to draw some conclusions about the real exchange rate overvaluation on the eve of the end-1994 crisis. We use the estimated long-run parameters that emerged from the dynamic model to derive a time series that represents the logarithm of the long-run equilibrium export real exchange rate. This shadow equilibrium real exchange rate can then be compared with the actual logarithm of the export real exchange rate to calculate the magnitude of the overvaluation on the eve of the end-1994 crisis.

We calculated two shadow logarithms of the exports real exchange rate: one was calculated based on the parameters estimated for the whole sample period of 1982:1-98:4, while the other was calculated based on the parameters estimated for the period 1982:1-94:4. Thus, the second calculation excludes the effect of the structural break of 1995. When including the effect of the structural break, the peso was overvalued by about 25 percent on the eve of the end-1994 crisis, it then overshot in early 1995; however, when excluding the effect of the structural break, the peso was overvalued only by about 12 percent on the eve of the end-1994 crisis, it then overshot in early 1995.

### **V. SUMMARY, CONCLUSIONS, AND POLICY IMPLICATIONS**

After the 1980s, capital flows have accelerated in developing countries and since Salter's seminal paper in 1959, it has been widely accepted that the real exchange rate responds to capital flows and other relevant variables. Based on a model derived by Sjaastad and Manzur (1996), along the lines of Salter (1959), Khan and Montiel (1987), and Rodriguez (1994), we estimated the response of the export (and true) real exchange rate in Mexico to a set of explanatory variables for the period 1982:1-98:4 using static and dynamic models.

The study shows that in Mexico, there is a long-run relationship between the export (and true) real exchange rate and capital flows, the external terms of trade, and productivity in the manufacturing sector. The ratio of quarterly net capital inflows to quarterly (annualized) GDP seems to be the most important variable in accounting for the variability of the real exchange rate. Other things equal, a once and for all unit increase in that ratio leads to a long-run real appreciation of the peso (defined by the export real exchange rate) of about 12 percent. Disequilibria are corrected over time in a relatively quick manner—40 percent of a disequilibrium originated in a given quarter is corrected in the next quarter.

The analysis also reveals a structural break in 1995, which coincides with the adoption of a floating exchange rate arrangement. Estimated coefficients were relatively

Figure 5  
Actual and Fited Values of the First Difference of RERX, and Residual from the Estimate  
of the Equilibrium-Correction Single-Equation Model for the Period 1981:2-98:4

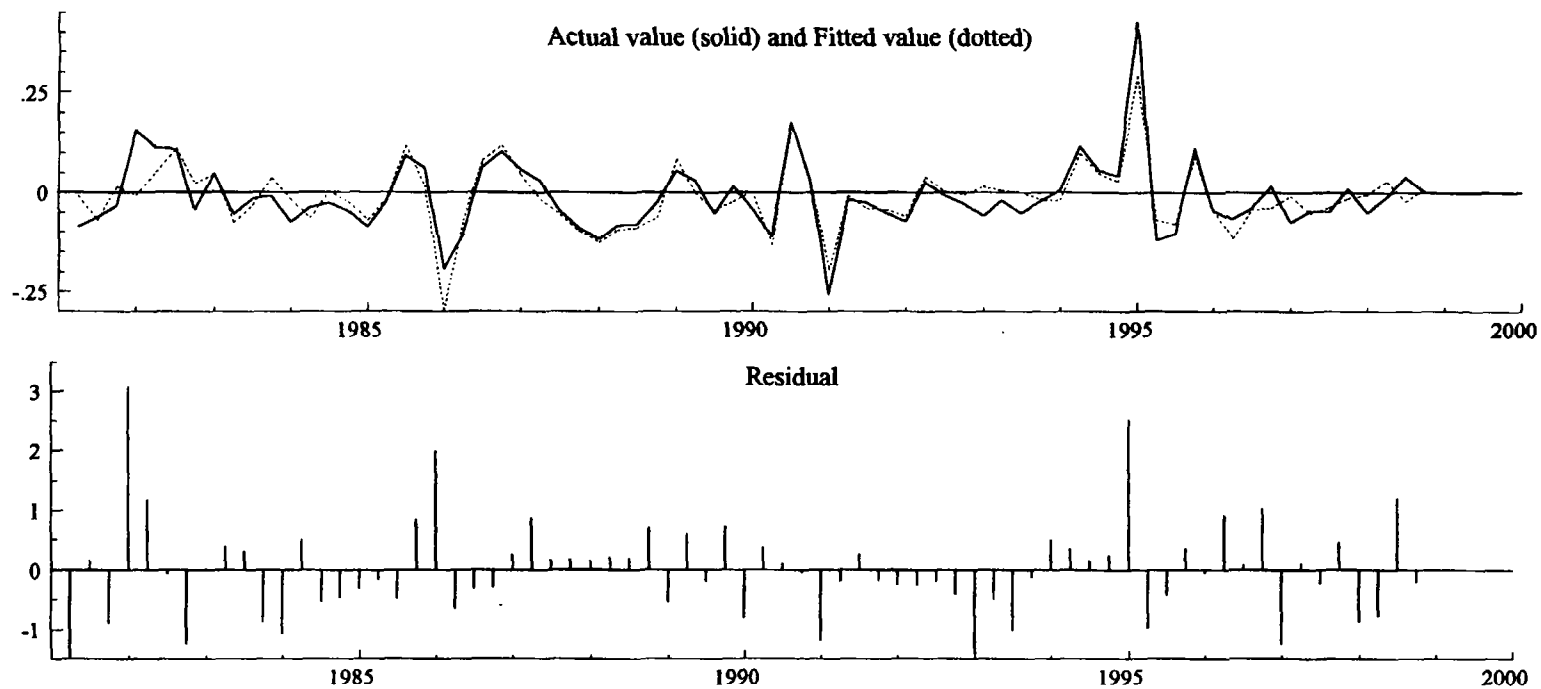
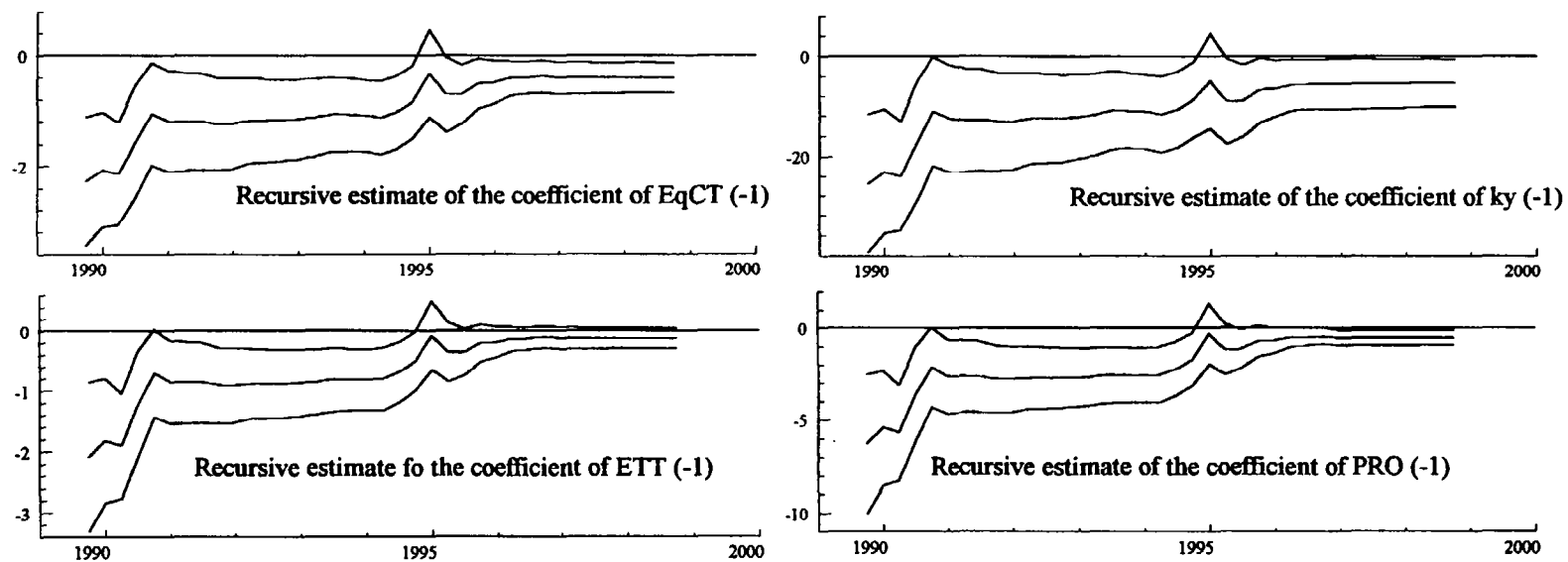


Figure 6  
Recursive Estimates of Key Coefficients of the  
Equilibrium-Correction Single-Equation Model for the Period 1981:2-98:4



stable until 1995 when they jumped to a new plateau and remained stable thereafter. On the eve of the end-1994 crisis, the peso was overvalued by about 12 percent when calculated using the estimated coefficients estimated before the structural break, and by about 25 percent when including the effect of the structural break.

Movements in the real exchange rate in Mexico have consistently responded to fluctuations in a few relevant variables, even under different exchange rate arrangements, including the current float. As the current arrangement has worked fairly well in accommodating macroeconomic shocks, and movements in the real exchange rate are still determined by movements in the same few and well-identified variables, we would guess that the current floating arrangement constitutes a viable regime also for the long run.

Although Mexico did further open its current account in mid-1980s, the data do not support the hypothesis that capital flows have less impact on the real exchange rate when the economy is more open. However, it would be interesting to revisit this hypothesis as more evidence accumulates, given that Mexico continues opening up its economy.<sup>10</sup>

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<sup>10</sup> Mexico can still implement further trade liberalization. Although its economy has become more open since the mid-80s, Mexico has not yet reached the degree of openness of, for example, either Australia or Canada. Since 1993, Mexico's strategy as regards trade liberalization is centered on free trade agreements. Following NAFTA, Mexico concluded free agreements with five Central and South American countries and the European Union, and it has shown interest in participating in the Asia-Pacific Economic Cooperation Council (APEC).



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### Derivation of the Relationship Among the True Real Exchange Rate, Capital Inflows and Productivity

The basic model used to derive the theoretical relation between capital inflows and the true real exchange rate is borrowed from Sjaastad and Manzur (1996).<sup>1</sup> To study the effect of capital flows, the terms of trade, and productivity on the real exchange rate, the model has three goods, importable, exportable, and home goods, and hence two relative prices. The price indices in domestic currency for imports of goods and nonfactor services, exports of goods and nonfactor services, and home goods are denoted by  $p_M$ ,  $p_X$  and  $p_H$ , respectively; and the value of imports and exports of goods and nonfactor services are  $m p_M$  and  $x p_X$ , respectively. The term  $y$  and  $y^e$  denotes GDP and expenditures on goods and nonfactor services, thus  $y^e = y + (m p_M - x p_X)$ . Net capital inflow, denoted by  $k$ , is defined as the capital account surplus minus net factor service payments abroad,  $k = y^e - y = m p_M - x p_X$ . The ratios of net capital inflow to the value of exports of goods and nonfactor services and to GDP is defined by  $k_x = k/x p_X$  and  $k_y = k/y$ , respectively.  $\gamma$ , a productivity factor, is defined as one plus the real change in productivity. Together with a closing identity, the model is:

$$m p_M = c_1 \left(\frac{p_M}{p_H}\right)^{-\alpha_H} \left(\frac{p_M}{p_X}\right)^{-\alpha_X} \left(\frac{y^e}{\gamma y}\right)^{1+\eta_M} \gamma y$$

$$x p_X = c_2 \left(\frac{p_X}{p_H}\right)^{\beta_H} \left(\frac{p_X}{p_M}\right)^{\beta_M} \left(\frac{\gamma y}{y^e}\right)^{\eta_X} \gamma y$$

$$m p_M = x p_X + k = x p_X (1 + k_x)$$

Expressing the system in a log-linear form (using upper case for natural logarithms), obtains:

$$M + P_M = C_1 + Y - (\alpha_H + \alpha_X) P_M + \alpha_H P_H + \alpha_X P_X + (1 + \eta_M) \ln(1 + k_y) + \eta_M \ln \gamma$$

$$X + P_X = C_2 + Y + (\beta_H + \beta_M) P_X - \beta_H P_H - \beta_M P_M - \eta_X \ln(1 + k_y) + \eta_X \ln \gamma + \ln \gamma$$

$$M + P_M = X + P_X + \ln(1 + k_X)$$

where  $\alpha_H$  and  $\alpha_X$  are the elasticities of import demand with respect to the price of imports relative to home goods and exports, respectively; and  $\beta_H$  and  $\beta_M$  are the elasticities of export

<sup>1</sup> We slightly modified their model to allow for productivity effect on the real exchange rate.

supply with respect to the price of exports relative to home goods and imports; and, in the absence of complementarity,  $\alpha_s$  and  $\beta_s$  are defined to be positive. Solving the log-linear system for  $P_H$ , and relabeling  $\ln \gamma$  as PRO yields the following reduced form:

$$P_H = C + \Theta [ (\eta_X + \eta_M + 1) \ln (1 + k_Y) - \ln (1 + k_X) ] + \omega P_M + (1 - \omega) P_X + \lambda \text{PRO}$$

where  $\Theta = -1/(\alpha_H + \beta_H)$ ,  $\omega = (\alpha_H + \alpha_X - \beta_M) / (\alpha_H + \beta_H)$ , and  $\lambda = (1 + \eta_X - \eta_M) / (\alpha_H + \beta_H)$ .

The absence of complementarity (i.e., given  $P_M$  and  $P_X$ , a change in  $P_H$  shifts expenditures and production in the "right" directions) ensures that  $\alpha_H + \beta_H > 0$ , which implies that  $\Theta$  is negative. Moreover,  $\omega$ , the elasticity of the price of home goods with respect to import prices, is the well known "shift" parameter in the theory of the incidence of protection (Sjaastad, 1980, and Rodriguez and Sjaastad, 1979).  $\lambda$  could be larger or smaller than zero; it would be larger than zero if an increase in productivity results in a larger increase in exports than in imports. In this case, the price of home goods relative to the price of exports and to the price of imports both rise (i.e., a real appreciation) to restore equilibrium.

The final term in the latter equation,  $\omega P_M + (1 - \omega) P_X$ , turns out to be exactly the appropriate price index for traded goods, and hence that equation is an implicit relationship between the *true* real exchange rate and capital inflows. The true real exchange rate,  $\text{trer}$ , is merely the relative price of traded goods to home goods and is defined, in logarithm, as  $\text{TRER} = P_T - P_H$ . The index  $P_T$  is a weighted average of  $P_X$  and  $P_M$ . Sjaastad and Manzur (1996) show that if the homogeneity postulate is to be satisfied, then  $dP_T/dP_M = \omega$  and  $dP_T/dP_X = 1 - \omega$ , and therefore  $P_T = \omega P_M + (1 - \omega) P_X$  and the  $\text{TRER} = \omega P_M + (1 - \omega) P_X - P_H$ . Accordingly, the above reduced form can be written as an explicit relationship between the true real exchange rate and capital inflows:

$$\text{TRER} = \text{constant} + \Theta \{ \ln [(1 + k_X)/(1 + k_Y)] - (\eta_X + \eta_M) \ln (1 + k_Y) \} - \lambda \text{PRO}$$

Since  $\eta_X$  and  $\eta_M$  are likely to be small, their sum is also likely to be small; in addition, since  $\ln (1 + k_Y)$  is approximately  $k_Y$  which also is small, the product  $(\eta_X + \eta_M) \ln (1 + k_Y)$  will be neglected in what follows. Moreover, as  $\ln [(1 + k_X)/(1 + k_Y)]$  is approximately  $k_X - k_Y$ , the reduced form can be written as:

$$\text{TRER} = \text{constant} + \Theta (k_X - k_Y) - \lambda \text{PRO}$$

Defining  $z = E \times p_X / \text{GDP}$ , then  $k_X - k_Y = [(1 - z)/z] k_Y$  and replacing the last expression, obtains equation (1) of the text:

$$\text{TRER} = \text{constant} + \Theta_y \cdot k_Y - \lambda \text{PRO}$$

where  $\Theta_y = \{(1 - z)/z\} \Theta$ . The ratio of  $\Theta_y$  to  $\Theta$ , which can alternatively be expressed as  $(\text{GDP}/E \times p_X) - 1$ , measures the degree of openness of the economy. The lower this ratio is, the more open the economy.

**Augmented Dickey-Fuller Test on the Levels and First Differences  
of the Variables in Equation 2**

**Table 4. Augmented Dickey-Fuller Test on the Levels and First Differences  
of the Variables in Equation 2 for the period 1970:1-98:4**

Variable	Test Value	1% Critical Value	5% Critical Value	Decision
RERX	-0.93	-3.49	-2.89	Is not I(0)
RERM	-2.66	-3.49	-2.89	Is not I(0)
$k_y$	-2.57	-3.49	-2.89	Is not I(0)
ETT	-0.48	-3.49	-2.89	Is not I(0)
$\Delta$ RERX	-4.87	-3.49	-2.89	Is I(0)
$\Delta$ RERM	-4.85	-3.49	-2.89	Is I(0)
$\Delta k_y$	-4.75	-3.49	-2.89	Is I(0)
$\Delta$ ETT	-5.00	-3.49	-2.89	Is I(0)

**Table 5. Augmented Dickey-Fuller Test on the Levels and First Differences  
of the Variables in Equation 2 for the period 1982:1-98:4**

Variable	Test Value	1% Critical	5 % Critical	Decision
RERX	-1.64	-3.54	-2.91	Is not I (0)
RERM	-1.94	-3.54	-2.91	Is not I (0)
$k_y$	-2.07	-3.54	-2.91	Is not I (0)
ETT	-2.28	-3.54	-2.91	Is not I (0)
PRO	0.76	-3.54	-2.91	Is not I (0)
$\Delta$ RERX	-3.59	-3.54	-2.91	Is I (0)
$\Delta$ RERM	-3.63	-3.54	-2.91	Is I (0)
$\Delta k_y$	-3.99	-3.54	-2.91	Is I (0)
$\Delta$ ETT	-4.07	-3.54	-2.91	Is I (0)
$\Delta$ PRO	-3.07	-3.54	-2.91	Is I (0) at 5 %

The ADF tests reveal that the variables in equation 2 are integrated of order one,  $I(1)$ , for the periods of 1970:1-98:4 and 1982:1-98:4.

### Variability of $r_{erx}$ and $k_y$ Across Subperiods

In the second subperiod, Mexico underwent structural reforms including trade and price liberalization, as well as financial reforms. To assess the effect of these reforms on the variability of the real exchange rate and the ratio of capital inflow to GDP, we tested the null hypothesis of equality of the variances of  $r_{erx}$  and  $k_y$  across the subperiods of 1970:1-84:1 and 1984:2-98:4 (it is not necessary to assume that the two samples have equal means). We compute the ratio of the sample variances, which follows an F distribution, and reject the null hypothesis if this ratio is either unusually large or unusually small. The critical region for a 5 percent level of significance and for 57 and 59 observations in the first and second subperiods (or (56, 58) degree of freedoms) consist of values of  $F > F_{.975}(56,58) = 1.67$  and  $F < F_{.025}(56,58) = 0.6$ . And for a 1 percent level of significance, the critical region consist of values of  $F > F_{.995}(56,58) = 1.96$  and  $F < F_{.005}(56,58) = 0.510$ .

Table 6. Variances and Ratios

	1970:1-84:1 Var <sub>1</sub>	1984:2-98:4 Var <sub>2</sub>	Ratio of variances (Var <sub>1</sub> /Var <sub>2</sub> )
$r_{erx}$	0.019219	0.0317527	0.6053
$k_y$	0.000085969	0.00008764	0.9809

Table 7. Tests for Equality of Variances

	F.005	F.025	Ratio of sample variances	F.975	F.995	Decision
$r_{erx}$	0.510	0.600	0.6053	1.67	1.96	Accept equality at 5% and 1%
$k_y$	0.510	0.600	0.9809	1.67	1.96	Accept equality at 5% and 1%

Thus, the test accepts the null hypothesis of no difference between the variances of  $k_y$  in each of the subperiods considered at the 5 and 1 percent significance levels. The same results obtained for  $r_{erx}$ .

### Difference in the Degree of Openness Across Subperiods

After 1984, Mexico started liberalizing its external current account. We constructed a series of a measure of the degree of openness given by (Exports + Imports) / GDP, where Exports includes net maquila exports. The means and variances of this series for the subperiods 1970:1-84:1, 1984:2-94:4, and 1984:2-98:4 are shown in Table 8. (we included a subperiod ending in the fourth quarter of 1994 to avoid the effect of the large devaluation at end 1994 on the degree of openness.) The higher mean of the degree of openness after 1984 would indicate that the economy was more open. To assess whether the greater openness was statistically significant, we tested the null hypothesis that the difference of the means prior and after trade liberalization is zero. We constructed the sampling distribution of the statistics  $z$ , which is normal distributed, and use a cumulative normal distribution table to determine the critical region (Table 9).

$$z = (\mu_1 - \mu_2) / \sqrt{\left( \frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2} \right)}$$

Table 8. Level and Variability of the Degree of Openness

	Mean	Variance	Number of observations
1970:1-1984:1	21.43	10.09	57
1984:2-1994:4	28.44	5.93	43
1984:2-1998:4	32.37	46.62	59

Table 9. Test for the Differences in Means

	Z.005	Z.025	Z value	Z.975	Z.995	Decision
1970:1-1984:1 vs. 1984:2-1998:4	-2.55	-1.95	-11.12	1.95	2.55	Reject equality at 5% and 1%
1970:1-1984:1 vs. 1984:2-1994:4	-2.55	-1.95	-12.49	1.95	2.55	Reject equality at 5% and 1%



The test rejects the null hypothesis at the 5 percent and 1 percent significance level, implying that the Mexican economy has had a higher degree of openness after 1984.

### Error Correction Representation of the Autoregressive-Distributed-Lag Model

Consider the following autoregressive-distributed-lag model:

$$Y_t = \alpha_1 Y_{t-1} + \alpha_2 Y_{t-2} + \alpha_3 Y_{t-3} + \alpha_4 Y_{t-4} + \beta_0 X_t + \beta_1 X_{t-1} + \beta_2 X_{t-2} + \beta_3 X_{t-3} + \beta_4 X_{t-4} \quad (1)$$

$$+ \text{constant} + \varepsilon_t$$

Subtracting  $Y_{t-1}$  on the both members of (1), and adding and subtracting some specific terms on the RHS of (1), obtains:

$$\begin{aligned} Y_t - Y_{t-1} &= \alpha_1 Y_{t-1} - Y_{t-1} + (\alpha_2 Y_{t-1} - \alpha_2 Y_{t-1}) + (\alpha_3 Y_{t-1} - \alpha_3 Y_{t-1}) + (\alpha_4 Y_{t-1} - \alpha_4 Y_{t-1}) \\ &\quad + \alpha_2 Y_{t-2} + (\alpha_3 Y_{t-2} - \alpha_3 Y_{t-2}) + \alpha_3 Y_{t-3} + (\alpha_4 Y_{t-3} - \alpha_4 Y_{t-3}) + \alpha_4 Y_{t-4} \\ &\quad + \beta_0 X_t + (\beta_0 X_{t-1} - \beta_0 X_{t-1}) + \beta_1 X_{t-1} + (\beta_2 X_{t-1} - \beta_2 X_{t-1}) + (\beta_3 X_{t-1} - \beta_3 X_{t-1}) \\ &\quad + (\beta_4 X_{t-1} - \beta_4 X_{t-1}) + \beta_2 X_{t-2} + (\beta_3 X_{t-2} - \beta_3 X_{t-2}) + \beta_3 X_{t-3} + (\beta_4 X_{t-3} - \beta_4 X_{t-3}) \\ &\quad + \beta_4 X_{t-4} + \text{constant} + \varepsilon_t \end{aligned}$$

rearranging and collecting terms, yields:

$$\begin{aligned} Y_t - Y_{t-1} &= (\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 - 1) Y_{t-1} - \alpha_2 (Y_{t-1} - Y_{t-2}) - \alpha_3 (Y_{t-1} - Y_{t-2}) - \alpha_4 (Y_{t-1} - Y_{t-2}) \quad (2) \\ &\quad - \alpha_3 (Y_{t-2} - Y_{t-3}) - \alpha_4 (Y_{t-2} - Y_{t-3}) - \alpha_4 (Y_{t-3} - Y_{t-4}) + \beta_0 (X_t - X_{t-1}) \\ &\quad - (\beta_0 + \beta_1 + \beta_2 + \beta_3 + \beta_4) X_{t-1} - \beta_2 (X_{t-1} - X_{t-2}) - \beta_3 (X_{t-1} - X_{t-2}) \\ &\quad - \beta_4 (X_{t-1} - X_{t-2}) - \beta_3 (X_{t-2} - X_{t-3}) - \beta_4 (X_{t-2} - X_{t-3}) + \beta_4 (X_{t-3} - X_{t-4}) \\ &\quad + \text{constant} + \varepsilon_t \end{aligned}$$

using the change operator,  $\Delta$ , and collecting terms, obtains:

$$\begin{aligned} \Delta Y_t &= (\Sigma\alpha - 1) Y_{t-1} + \Sigma\beta X_{t-1} - (\alpha_2 + \alpha_3 + \alpha_4) \Delta Y_{t-1} - (\alpha_3 + \alpha_4) \Delta Y_{t-2} \quad (3) \\ &\quad - \alpha_4 \Delta Y_{t-3} + \beta_0 \Delta X_t - (\beta_2 + \beta_3 + \beta_4) \Delta X_{t-1} - (\beta_3 + \beta_4) \Delta X_{t-2} - \beta_4 \Delta X_{t-3} \\ &\quad + \text{constant} + \varepsilon_t \end{aligned}$$

$$\Delta Y_t = (\Sigma\alpha - 1) [Y_{t-1} - (\Sigma\beta / (1 - \Sigma\alpha)) X_{t-1}] - (\alpha_2 + \alpha_3 + \alpha_4) \Delta Y_{t-1} - (\alpha_3 + \alpha_4) \Delta Y_{t-2} \quad (4)$$

$$\begin{aligned}
 & -\alpha_4 \Delta Y_{t-3} + \beta_0 \Delta X_t - (\beta_2 + \beta_3 + \beta_4) \Delta X_{t-1} - (\beta_3 + \beta_4) \Delta X_{t-2} - \beta_4 \Delta X_{t-3} \\
 & + \text{constant} + \varepsilon_t
 \end{aligned}$$

Since the parameters in the long-run equilibrium are not known, a further transformation is considered in practice: adding and subtracting  $(\Sigma\alpha-1) X_{t-1}$  on the RHS of (3), obtains:

$$\begin{aligned}
 \Delta Y_t = & (\Sigma\alpha-1) [Y_{t-1} - X_{t-1}] + (\Sigma\alpha + \Sigma\beta -1) X_{t-1} - (\alpha_2 + \alpha_3 + \alpha_4) \Delta Y_{t-1} - (\alpha_3 + \alpha_4) \Delta Y_{t-2} \quad (5) \\
 & -\alpha_4 \Delta Y_{t-3} + \beta_0 \Delta X_t - (\beta_2 + \beta_3 + \beta_4) \Delta X_{t-1} - (\beta_3 + \beta_4) \Delta X_{t-2} - \beta_4 \Delta X_{t-3} \\
 & + \text{constant} + \varepsilon_t
 \end{aligned}$$

A generalization of equation 5 (for more variables) is estimated in Table 3 in the text.