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Estimating Pass-Through: Structure and Stability

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ABSTRACT

This paper estimates the pass-through relationship between exchange rates and import prices for the United States using recursive techniques across a variety of specifications to examine structural and coefficient stability in a systematic fashion. Results of estimations: 1) indicate that pass-through at the macroeconomic level is a complicated amalgamation of disparate industrial structures that involves more than one long-run equilibrium relationship between the variables of interest, and 2) call into question the prevailing wisdom that foreign firms changed their pricing behavior in light of the large appreciation in the exchange value of the dollar in the early 1980s.

Estimating Pass-Through: Structure and Stability

William R. Melick[1]

Two issues have dominated studies of the "pass-through" of exchange rate changes into aggregate dollar import prices: the size of the pass-through coefficient (both in the short-run and the long-run) and the stability of the pass-through relationship. In this paper the pass-through relationship is estimated using recursive techniques across a variety of econometric specifications to examine structural and coefficient stability in a systematic fashion. This approach allows for a careful analysis of the stability issue, and it also provides estimates of the size of the pass-through coefficient. The main conclusions of the paper are: (1) pass-through at the macroeconomic level is a complicated amalgamation of disparate industrial structures that involves more than one long-run equilibrium relationship between the variables of interest, and (2), claims of changes in the aggregate behavior of foreign firms in response to the large dollar appreciation in the early 1980s may be unfounded.

The paper begins with a presentation of three simple theoretical models of pass-through. The second section presents the results of estimating the pass-through relationship using the Johansen (1990)

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1. The author is a staff economist in the Division of International Finance. This paper represents the views of the author and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System or other members of its staff. I especially thank Peter Hooper and Catherine Mann both for helpful comments and the generous provision of their data set. I also thank Marc Dudey, Hali Edison, Neil Ericsson, Dale Henderson, David Hendry, David Howard, Eric Leeper, Ellen Meade, Andrew Rose, Charles Thomas, Charles Whiteman, and participants in the International Finance Division's Monday Workshop series. Elizabeth Vrankovich provided valuable research assistance.

procedure, a vector auto-regressive (VAR) approach that allows for non-stationary variables. The results from the simpler single-equation Engle-Granger (1987) (E-G) procedure are presented in the third section. The E-G results allow for a close comparison with a re-estimation of a more traditional specification, found in the fourth section. Conclusions are presented in the fifth section.

I. Simple Models of Pass-Through

A variety of models of the pricing behavior of foreign firms in the U.S. market have been specified, including, among many others, Hooper and Mann (1989) (henceforth H-M), Baldwin (1988), and Dornbusch (1987). These models focus only on costs, exchange rates, and prices, ignoring income and other variables that would be present in a reduced form solution to a supply and demand formulation. A general specification, using variables typically found in the literature can be written as

$$(1)\quad PM = f(ER, PD, CF, CD)$$

where

PM = the price of imports measured in dollars
ER = the exchange rate, foreign currency per dollar
PD = competing domestic prices, in dollars
CF = foreign unit costs, measured in foreign currency
CD = domestic unit costs, measured in dollars

Three simple theoretical models illustrate the variety of long-run relationships that might exist between the variables found in (1).

Consider first a competitive specification. In such a world free entry and exit and goods arbitrage would produce three long-run relationships: in each country the rate of return (profits divided by total costs) should yield zero economic profit, and purchasing power parity. These three conditions can be written as

$$(2)\quad \frac{PD}{CD} = 1 + r^d$$

$$(3)\quad \frac{PM*ER}{CF} = 1 + r^f$$

$$(4)\quad \frac{PM}{PD} = 1$$

where r^f and r^d are the rates of return in the foreign and domestic countries that ensure zero economic profits. If these two rates of return were equal, (2) and (3) would imply, using (4) to eliminate PM and PD,

$$(5)\quad CF = ER*CD \quad .$$

In such a world, a change in the exchange rate, in the long-run, would have no effect on import prices. Rather, the relative number of foreign firms would change as movements in the exchange rate altered the cost competitiveness of foreign firms.

Alternatively, one could use any of a wide variety of imperfectly competitive models. For example, consider a domestic firm and a foreign, both Nash price competitors, selling two differentiated products. Linear demand curves (f for foreign and d for domestic) for each of the firms are given by

$$(6)\quad Q_f = -a_1PM + b_1PD \qquad a_1, b_1 > 0$$

$$(7)\quad Q_d = +b_2PM - a_2PD \qquad a_2, b_2 > 0$$

Profits for the two firms would then be given by

$$(8)\quad \Pi_f = (-a_1PM + b_1PD)(PM*ER - CF)$$

$$(9)\quad \Pi_d = (b_2PM - a_2PD)(PD - CD).$$

Differentiating (8) and (9) with respect to PM and PD (assuming that unit costs do not depend on output), setting the derivatives equal to zero, and solving for PM and PD yields[2]

2. An assumption about the functional form of the total cost function for each firm, $TC_i = g_i(Q_i)$, would eliminate CF and CD from the solutions for PD and PM.

$$(10)\quad PM = \frac{2a_2}{4a_1a_2-b_1b_2}\left[\frac{b_1CD}{2} + \frac{a_1CF}{ER}\right]$$

$$(11)\quad PD = \frac{2a_1}{4a_1a_2-b_1b_2}\left[\frac{b_2CF}{2ER} + a_2CD\right].$$

The pass-through coefficient for this model is found by differentiating (10) with respect to ER, which when expressed as an elasticity yields

$$(12)\quad \frac{\partial PM}{\partial ER}*\frac{ER}{PM} = \frac{-2a_2a_1}{4a_1a_2-b_1b_2}\left(\frac{CF}{PM*ER}\right) .$$

Using (10) to substitute for PM on the right-hand side reduces the expression to

$$(13)\quad \frac{\partial PM}{\partial ER}*\frac{ER}{PM} = \frac{-1}{\frac{ER*CD}{2a_1*CF} + 1} .$$

Polar cases for (13) can be considered. Setting a_1 equal to infinity (the foreign firm is a price-taker) yields the pass-through coefficient of -1, exchange rate changes are fully offset. Setting a_1 equal to zero (demand for the foreign firm's product is unaffected by the price it charges) results in a pass-through coefficient of zero.

The H-M mark-up model is a second imperfectly competitive formulation. The mark-up of price over cost is given by

$$(14)\quad PM = \lambda\frac{CF}{ER}$$

The mark-up, λ, is variable and responds to the difference between competing domestic prices and foreign costs in dollars, as well as to changes in foreign capacity utilization (CU). This can be written as

$$(15)\quad PM = \left[\left(\frac{PD}{CF/ER}\right)^{\alpha}*(CU)^{\beta}\right]*\frac{CF}{ER} .$$

Again polar cases can be considered. Setting α equal to 1 and β equal to zero transforms (15) into the purchasing power parity condition found in (4) of the perfectly competitive model. Exchange rates have no effect on import prices. Setting α and β equal to zero yields complete pass-through as exchange rate changes are entirely offset.

These three simple models suggest the wide variety of long-run relationships that might be expected to hold between the five variables in (1). The point to be taken from this discussion is that any econometric work should proceed in as general a fashion as possible, allowing for the possibility of several unique relationships among the variables in the data set.

II. Johansen Procedure

The Johansen (1990) procedure is extremely general and therefore meets the estimation requirements outlined above. It is also allows for, but does not require, non-stationary variables integrated of order one.[3] This is an important consideration given the data considered here (see Charts 1-5, and Appendix III below). The procedure analyzes the relationship among p I(1) or I(0) variables using the following VAR system

$$(16) \quad \Delta X_t = \Gamma_1 \Delta X_{t-1} + \dots + \Gamma_{k-1} \Delta X_{t-(k-1)} - \Pi X_{t-k} + \mu + \phi D_t + \epsilon_t,$$

where X_t is a (p,1) vector of observations on the p variables at time t. D_t is a (p,3) matrix of centered, seasonal, dummy variables[4], μ is a (p,1) vector of constant terms for each equation. The matrices Γ_i and Π are (p,p) matrices of coefficients, and ϵ is a (p,1) vector of error terms.

The matrix Π captures the long-run relationships between the p variables, and there are three possibilities for it

1. Rank of Π = p, vector process X is stationary.

3. A stationary variable is said to be integrated of order zero, denoted I(0). A non-stationary variable that is rendered stationary by first differences is I(1).

4. A centered, seasonal dummy variable sums to zero over a year's time.

2. Rank of $\Pi = 0$, Π is the null matrix, ΔX is stationary.
3. Rank of $\Pi = r < p$, there are r linear combinations of X that are stationary, i.e. that are co-integrated.

In the Johansen procedure, the rank of Π is determined by calculating its p eigenvalues and determining if they are different than zero in a statistical sense.[5] The number of non-zero eigenvalues provides an estimate of r, the number of co-integrating vectors. If $0<r<p$, then Π can be decomposed into two (p,r) matrices α and β such that

$$(17) \quad \Pi = \alpha\beta'.$$

It is important to emphasize that these matrices are not unique. Appendix I gives a simple example to clarify these ideas. The matrix β consists of the r (p,1) co-integrating vectors[6] while α, termed the loadings by Johansen, are the coefficients on the co-integrating vector(s) in each of the p equations.

Johansen provides two tests for determining the number of co-integrating vectors. The first is an unconditional test of the form Ho: $r \leq i$, while the second is a conditional test of the form Ho: $r=i|r=j$, $j>i$. Johansen also develops procedures to test linear restrictions imposed across the coefficients of α and β, and to test the restriction that the constant terms μ can be incorporated into β, the co-integrating vectors.

The quarterly data set found in H-M, augmented with the domestic cost variable CD, was used in all estimations in this paper (see Appendix II). The data set contains 62 observations, beginning in first quarter of 1973 (73:1) and ending in the second quarter of 1988 (88:2). Charts 1-5

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5. The procedure actually considers a transformation of Π that restricts all the eigenvalues to be real numbers between 0 and 1.
6. Under certain restrictions the constant terms in (2) can be incorporated in the co-integrating vectors, yielding co-integrating vectors of dimension (p+1,1).

plot the natural logarithms of the five variables (lower case letters denote variables expressed as natural logarithms). In order to implement the Johansen procedure one must choose a value for k, the number of lags in (16). Unfortunately the procedure can be sensitive to the choice of k.[7]

Table 1 presents the results of analyzing the 5 variable system of pm, er, cf. pd, and cd (the variables found in the competitive model), setting k = 2, 3, and 4 to address the sensitivity question.[8] The top half of Table 1 presents the estimated eigenvalues and the conditional and unconditional hypothesis tests on the value of r, the number of co-integrating vectors. Starred values indicate a rejection of the null hypothesis shown on the left-hand side of the table at the 5% significance level. It seems clear that the procedure is identifying two co-integrating vectors among these variables. Although not shown in Table 1, a test of the restrictions involved in including a constant term in the co-integrating vector(s) was rejected for all values of k.

The two significant co-integrating vectors, the estimate of β, are given in the table, with the coefficient on pm normalized to equal -1 in both vectors. Economic explanations of the coefficients in these vectors is difficult at best: the procedure cannot uniquely identify co-integrating vectors since any linear combination of co-integrating vectors is also a valid co-integrating vector. Interpretation must be guided by an underlying theoretical model, a task complicated by the

7. This is true for other data sets than that considered here. Using the data in Johansen and Juselius and setting k=3 rather than k=2 reverses some of their conclusions (e.g. money and income homogeneity in Denmark would have been rejected).
8. The Johansen procedure was coded in GAUSS. The program was checked by replicating to the fourth digit the results of Johansen and Juselius.

Table 1

	K, Longest lag in Johansen VAR: 2		3		4	
Eigenvalues						
	0.023		0.047		0.057	
	0.097		0.065		0.144	
	0.310		0.265		0.267	
	0.392		0.468		0.454	
	0.504		0.492		0.641	
Unconditional Hypothesis Tests, Trace						
Ho: $r \leq 4$	1.375		2.839		3.390	
Ho: $r \leq 3$	7.525		6.808		12.416	
Ho: $r \leq 2$	29.831*		25.004*		30.427*	
Ho: $r \leq 1$	59.725*		62.201*		65.493*	
Ho: $r \leq 0$	101.810*		102.208*		124.858*	
Conditional Hypothesis Tests, Maximum Eigenvalue						
Ho: $r=4 \mid r=5$	1.375		2.839		3.390	
Ho: $r=3 \mid r=4$	6.150		3.969		9.025	
Ho: $r=2 \mid r=3$	22.306*		18.196*		18.011*	
Ho: $r=1 \mid r=2$	29.894*		37.198*		35.066*	
Ho: $r=0 \mid r=1$	42.084*		40.007*		59.365*	
Beta, assuming r = 2						
pm	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
er	0.935	-0.700	-0.591	-0.446	-0.615	-0.522
cf	5.511	1.217	-0.301	1.018	-0.694	0.809
pd	-2.877	-0.715	1.433	-0.004	1.795	0.020
cd	-2.089	0.463	-0.280	-0.146	-0.244	0.061

Hypothesis Tests of Restrictions Across Rows of β

Restriction	2	3	4
$-\beta_{i3} = \beta_{i2}$	6.516*	18.607*	38.080*
$\beta_{i5} = -(\beta_{i1} - \beta_{i2} + \beta_{i4})$	0.937	20.014*	22.896*
$-\beta_{i3} = \beta_{i2}$ and $\beta_{i5} = -(\beta_{i1} - \beta_{i2} + \beta_{i4})$	22.837*	42.439*	59.760*
$\beta_{i5} = 0$	4.426	3.935	4.893

*Denotes statistically different from zero at the 5 % signifigance level.

competing models. Therefore, the implications of each of the three models will be analyzed in turn.

Data generated in a competitive world would yield three co-integrating vectors corresponding to equations (2)-(4) However, the Johansen procedure would only be able to identify arbitrary linear combinations of the three vectors. Re-writing equations (2)-(4) in logarithmic form yields

(18) $pd - cd = \ln(1+r^d) \approx r^d$

(19) $pm + er - cf = \ln(1+r^f) \approx r^f$

(20) $pm - pd = 0$

An arbitrary linear combination of these relationships would be written as

$$(21)\quad \begin{array}{l} pm \\ er \\ cf \\ pd \\ cd \\ \text{constant} \end{array} \quad \tau \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \\ -1 \\ -r^d \end{bmatrix} + \sigma \begin{bmatrix} -1 \\ -1 \\ 1 \\ 0 \\ 0 \\ r^f \end{bmatrix} + \lambda \begin{bmatrix} -1 \\ 0 \\ 0 \\ 1 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} -\sigma-\lambda \\ -\sigma \\ \sigma \\ \tau+\lambda \\ -\tau \\ -\tau r^d+\sigma r^f \end{bmatrix}.$$

What is clear from the right-hand side of (21) is that even if the data were generated in a competitive world, one would not expect to find a zero coefficient on er in a co-integrating vector. The only testable restrictions on the co-integrating vectors are those that can be applied across all the co-integrating vectors, or put another way, the only testable restrictions are those that hold for an arbitrary linear combination of the co-integrating vectors. For the competitive model under consideration, two restrictions can be placed across the five rows of the right-hand side of (21). Denoting an element of a co-integrating vector by β_{ij} (i=column, j=row as in Johansen and Juselius and the opposite of standard matrix notation) the restrictions implicit in (21) can be written as

$$(22) \quad -\beta_{i3} = \beta_{i2}$$

$$(23) \quad \beta_{i5} = -(\beta_{i1}-\beta_{i2}+\beta_{i4}).$$

Tests of each of these restrictions are presented at the bottom of Table 1, along with a joint test of the two restrictions. In all cases but one the restrictions are overwhelmingly rejected.

Alternatively, the data might be generated in a non-competitive world described by (10) and (11), which for simplicity can be written as

$$(24) \quad PM = \phi CD + \kappa\frac{CF}{ER}$$

$$(25) \quad PD = \mu\frac{CF}{ER} + \kappa CD.$$

As above, an arbitrary linear combination of these vectors would be given by:

$$\begin{array}{l} PM \\ CF/ER \\ PD \\ CD \end{array} \qquad \tau\begin{bmatrix} -1 \\ \kappa \\ 0 \\ \phi \end{bmatrix} + \sigma\begin{bmatrix} 0 \\ \mu \\ -1 \\ \kappa \end{bmatrix} = \begin{bmatrix} -\tau \\ \tau\kappa+\sigma\mu \\ -\sigma \\ \tau\phi+\sigma\kappa \end{bmatrix}$$

Unlike the competitive case, no restrictions can be imposed on the rows of the linear combination of the co-integrating vectors. In this formulation the data are expressed in levels, and CF and ER do not enter independently in any of the co-integrating vectors. The system of PM, CF/ER, CF, PD, CD and constant was estimated to generate the restriction that the coefficient on CF be equal to zero in all co-integrating vectors. Table 2 presents results for this system, and the restriction that the coefficient on CF is equal to zero is rejected for lag lengths 3 and 4 but not 2.

Table 2

K, Longest lag in Johansen VAR

	2	3	4
Eigenvalues			
	0.0052	0.0006	0.0019
	0.1031	0.0737	0.0874
	0.2741	0.2656	0.2229
	0.3099	0.3970	0.3636
	0.4383	0.4644	0.5906
Unconditional Hypothesis Tests, Trace			
Ho: r≤4	0.314	0.036	0.111
Ho: r≤3	6.843	4.556	5.418
Ho: r≤2	26.065	22.772	20.044
Ho: r≤1	48.319	52.611*	46.261*
Ho: r≤0	82.928*	89.444*	98.065*
Conditional Hypothesis Tests, Maximum Eigenvalue			
Ho: r=4|r=5	0.314	0.036	0.111
Ho: r=3|r=4	6.530	4.520	5.307
Ho: r=2|r=3	19.221	18.215	14.627
Ho: r=1|r=2	22.254	29.840*	26.216
Ho: r=0|r=1	34.609	36.833*	51.804*

Beta, assuming r = 2

	2		3		4	
PM	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
CF/ER	-30.051	61.825	68.805	50.707	65.227	54.211
PD	-0.983	0.659	2.073	0.498	2.122	0.248
CD	-1.482	-0.091	-0.354	-0.226	-0.296	-0.014
CF	3.106	-0.318	-1.534	0.034	-1.579	0.083

Hypothesis Tests of Restrictions Across Rows of β

	2	3	4
$\beta_{i5} = 0$	3.796	17.116*	35.988*

*Denotes statistically different from zero at the 5 % signifigance level.

Table 3

K, Longest lag in Johansen VAR

	2	3	4
	Eigenvalues		
	0.048	0.056	0.065
	0.169	0.080	0.111
	0.330	0.422	0.377
	0.361	0.452	0.655
	Unconditional Hypothesis Tests, Trace		
Ho: $r \le 3$	2.927	3.412	3.915
Ho: $r \le 2$	13.999	8.306	10.721
Ho: $r \le 1$	38.048*	40.643*	38.166*
Ho: $r \le 0$	64.906*	76.169*	99.947*
	Conditional Hypothesis Tests, Maximum Eigenvalue		
Ho: $r=3 \mid r=4$	2.927	3.412	3.915
Ho: $r=2 \mid r=3$	11.073	4.894	6.806
Ho: $r=1 \mid r=2$	24.049*	32.337*	27.444
Ho: $r=0 \mid r=1$	26.858	35.526*	61.781*

Beta, assuming $r = 2$

	a	b	b	a	b	a
pm	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
er	-0.607	-0.660	-0.615	-0.548	-0.574	-0.577
cf	0.715	-0.526	-0.868	0.517	-0.315	0.726
pd	0.177	1.401	1.735	0.378	1.193	0.172
constant	3.257	3.672	3.501	2.966	3.219	3.081

Hypothesis Tests of Restrictions Across Rows of β

	2	3	4
$b_3 = -b_2$	6.789*	20.748*	43.600*
$b_4 = b_2 - b_1$	6.977*	17.704*	37.536*
$b_3 = -b_2$ and $b_4 = b_2 - b_1$	27.509*	43.304*	69.259*

*Denotes statistically different from zero at the 5 % signifigance level.

As a final possibility, the H-M model, (15), expressed in logarithms is given by[9]

(26) $pm = -(1-\alpha)er + (1-\alpha)cf + \alpha pd$,

yielding the co-integrating vector

$$\begin{array}{l} pm \\ er \\ cf \\ pd \end{array} \qquad \tau \begin{bmatrix} -1 \\ -(1-\alpha) \\ 1-\alpha \\ \alpha \end{bmatrix}.$$

Two restrictions can be placed on this vector,

(27) $\beta_3 = -\beta_2$

(28) $\beta_4 = \beta_2 - \beta_1$.

Moreover, this system can be nested within the five variable competitive system, the restriction that cd equals zero allowing the simplification to the four variable system. This restriction is never rejected (see the bottom of Table 1) and results for the four variable are presented in Table 3.[10] Again it appears that the system possesses two co-integrating vectors, rather than the one vector suggested by the H-M model. As shown at the bottom of the table, the restrictions in (27) and (28) are soundly rejected.

None of the models seems to stand-up to the scrutiny of the data, not a surprising result given the simplicity of the models and the aggregate nature of the data. Across the data set, firms in industries probably range from near perfect competitors to near monopolists. Such a disparity of industrial structures, when aggregated, might well be expected to yield a pass-through coefficient somewhere between zero and

9. The capacity utilization variable used by H-M is ignored here, as it never entered significantly in any of their results.
10. In contrast to the first two systems, for the H-M system the constant terms can be incorporated into the co-integrating vectors for any value of k.

one as well as more than one co-integrating relationship. This suggests that more fruitful studies of pass-through are probably best conducted at the industry level, where known market structures can be brought to bear on the problem (e.g. Knetter (1989)). It is interesting to note that the indication of two co-integrating vectors is robust across specifications. Additionally, in Table 3, regardless of the value of k, one of the vectors yields coefficients close to the typical pass-through results obtained using single-equation methods (see Sections III and IV below). Averaging the three vectors labeled "a" in Table 3 yields the vector

pm	-1.00
er	-.58
cf	.65
pd	.24
constant	3.10

The coefficients indicate that, in the long-run, firms pass-through approximately 60 percent of a change in either exchange rates or costs. The coefficient on pd suggests that they react very little to a change in competing domestic firms' prices.

Some researchers have formulated models of hysteresis in import prices, occasionally testing the models by looking for instability in estimated pass-through equations (e.g. Baldwin). A similar exercise can be conducted here, by estimating the Johansen procedure recursively. Such estimation generated the break-point Chow tests for each equation of (14) found in Charts 6-9.[11] Only the equation for pd exhibits any instability,

11. Let RSS_t stand for the residual sum of squares for an estimation whose sample ends at time t. Let RSS_T equal the residual sum of squares over the entire sample. The break-point Chow test used throughout this study compares RSS_t to RSS_T, correcting for different degrees of freedom. A series of Chow tests is created in a recursive estimation as t moves

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and at that only for one time period. Chart 10 plots the average of the coefficients on er from the two co-integrating vectors in Table 3 as sample size increases, setting k=3. Somewhat surprisingly, given the stability results for the individual equations, this average has been far from constant over time, although perhaps it has been in a statistical sense if its standard errors were large enough. The results on stability are mixed, but indications of instability do not appear to be related to exchange rate changes. This is in contrast to the results of earlier work (e.g. Baldwin, Piggot and Reinhart, Mastropasqua and Vona, and in some cases H-M). However, given the different estimation techniques, it is difficult to compare the results presented here with previous work. The next section will focus on single-equation estimations using the variables in the H-M specification to facilitate comparisons with previous work. The switch to simpler methods is not without costs, as these methods only allow for the identification of a single co-integrating vector. Given the fairly consistent finding of two co-integrating vectors, the single-equation results might well be an over-simplification.

III. E-G Procedure

An alternative estimation strategy to attempt to identify a co-integrating vector among these potentially I(1) variables is the E-G two-step procedure. However, the E-G procedure is not without its

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towards T. The final point plotted compares RSS_{T-1} to RSS_T. The graph plots this series of Chow tests, each divided by its appropriate 5% critical value. Thus, points that lie above 1.0 are periods for which the null hypothesis of a constant structure are rejected.

drawbacks. Unlike the Johansen procedure, the E-G procedure allows for only one co-integrating vector, and each variable in the system must be I(1) and not I(0).[12]

In order to allow for comparisons to earlier work, the four variable system of H-M was estimated using the E-G technique. The first stage estimation yielded

(29) $pm_t = 2.531 - .586\ er_t + .652\ cf_t + .405\ pd_t - .003$ trend

$R^2 = .997,\ \sigma = .0127780,\ DW = 1.194$

RSS = .0093068484 for 5 variables and 62 observations (73:1-88:2).

This equation corresponds to (26). The signs of the coefficients are as expected, dollar prices fall with an appreciation of the dollar, rise with an increase in foreign costs, and rise with an increase in the price of competing goods. The coefficients suggest that 60 percent of an exchange rate change is passed through to import prices, with a similar movement in response to a change in costs. Only 40 percent of a change in domestic prices is reflected in a change in import prices. Comparing (29) to (26) gives three estimates of α from the H-M model, respectively they are .413, .630, and .544. As noted above, these coefficients are quite close to the average of the vectors labelled "a" in Table 3.

To test if the residuals from (29) were I(0), an augmented Dickey-Fuller test (ADF) was run resulting in (t-ratios in parentheses, significance levels in brackets)

12. A vector consisting of one I(0) variable is trivially a co-integrating vector. Therefore, since the E-G procedure can only identify one co-integrating vector it is important not to mistakenly include I(0) variables that will confound this identification. Appendix III presents common unit root tests as well as the alternative trend stationary test proposed by DeJong, Nankervis, Savin, and Whiteman (1989) (DNSW) for each variable. As is often the case, it is impossible for almost all of the variables to determine whether or not the variable is I(0) or I(1).

$$(30) \quad \Delta\hat{u}_t = .0003 - .605\ \hat{u}_{t-1}$$
$$(.18) \quad (-5.01)$$

$R^2 = .299, \quad \sigma = .0114881, \quad DW = 1.874$

RSS = .0077865429 for 2 variables and 61 observations (73:2-88:2).

The t-statistic is above the critical value of 4.67 found in MacKinnon (1990), indicating that a unit root hypothesis is rejected for these residuals.[13] A general to simple approach was used to derive the specification for the second-stage error-correction equation. The steps taken from this general model to arrive at the final specification are shown in Table 4. Across the table, sample size is constant at 57 observations, 74:2-88:2. For each of the steps all the coefficients and their t-ratios are shown, along with a battery of diagnostic tests conducted at each step.[14] A star denotes the rejection of the null hypothesis that the particular problem is absent. Also shown at the bottom of Table 4 are the F-tests of the restrictions imposed in moving from the general to the final specification. The final specification was re-estimated over a slightly longer period, since the sample size was kept constant in moving from general to simple in Table 4, yielding

$$(31) \quad \Delta pm_t = -.003 + .165\ \Delta pm_{t-1} - .247\ \Delta er_t + .885\ \Delta pd_t - .384\ \hat{u}_{t-1}$$
$$(-1.09) \quad (2.01) \quad (-5.45) \quad (7.60) \quad (-5.61)$$
$$+ .003Q1 + .005Q2 - .001Q3$$
$$(.93) \quad (1.47) \quad (-.24)$$

$R^2 = .830, \quad \sigma = .0084469, \quad F(7,52) = 36.26\ [.0000], \quad DW = 2.104$

RSS = .0037101985 for 8 variables and 60 observations (73:3-88:2).

13. An LM test of serial correlation through the fourth lag on the residuals of (30) was insignificant.

14. The regressions were run in David Hendry's package PC-Give, where all these tests are calculated and displayed.

TABLE 4

	General		Intermediate		Simple	
	Coefficient	T-Ratio	Coefficient	T-Ratio	Coefficient	T-Ratio
Constant	-.008	-2.05	-.005	-2.13	-.004	-1.79
Δlpm_{t-1}	.225	1.31	.186	2.04	.208	2.61
Δlpm_{t-2}	-.018	-.11	-.045	-.47		
Δlpm_{t-3}	.252	1.65	.175	1.91		
Δlpm_{t-4}	-.118	-.83	-.144	-1.87		
Δler_{t}	-.295	-4.86	-.263	-6.05	-.251	-5.85
Δler_{t-1}	.057	.48				
Δler_{t-2}	.053	.51				
Δler_{t-3}	.102	1.12				
Δler_{t-4}	.008	.07				
Δlco_{t}	.118	.76				
Δlco_{t-1}	.056	.34				
Δlco_{t-2}	-.073	-.41				
Δlco_{t-3}	-.046	-.28				
Δlco_{t-4}	.092	.52				
Δlpd_{t}	.856	3.51	.953	8.08	.905	8.13
Δlpd_{t-1}	-.105	-.30				
Δlpd_{t-2}	-.057	-.17				
Δlpd_{t-3}	.254	.80				
Δlpd_{t-4}	-.253	-.92				
$\hat{u}_{t-1}$	-.526	-2.83	-.384	-5.22	-.400	-5.62
Q1	.009	1.54	.005	1.72	.005	1.58
Q2	.010	2.16	.007	2.30	.005	1.78
Q3	.003	.60	.002	.60	.001	.39
R^2	.899		.869		.855	
σ	.007890		.007619		.007755	
DW	1.839		1.797		1.880	
RSS	.002054		.002670		.002947	
LM,AR(4)	3.20*		.44		1.11	
ARCH(4)	.07		.31		.33	
J-B	.831		.926		.192	
LM,het.	.na		1.1371		1.2059	
RESET2	2.734		4.091*		2.803	
RESET3	1.801		2.107		1.509	
RESET4	1.219		1.768		1.058	

F-tests of Model Simplification

	Intermediate	Simple
General to Intermediate	F(13,33)=.76	
General to Simple		F(16,33)=.90
Intermediate to Simple		F(3,46)=1.59

* Denotes statistically different than zero at the 5 % level of signifigance

Test Descriptions

LM, AR(4): LM test for serial correlation from lags 1 to 4

ARCH(4): Engle's test for autoregressive conditional heteroskedasticity from lags 1 to 4.

J-B: Jarque Bera test for normality

LM, het.: LM test for heteroskedasticity

RESETi RESET test of adding the second through ith powers of $\hat{y}$ to the regression.

Given the interest in parameter stability generated by the hysteresis hypothesis, (31) was estimated recursively, generating Charts 11-13. Chart 11 plots the break-point Chow test for equation (31). Chart 12 plots the error-correction coefficient (the coefficient on $\hat{u}$) from (31) along with its standard errors, and Chart 13 does the same for the coefficient on Δer. As is quite obvious, this specification does not exhibit stability problems at any point in time. Ignoring the difficulties in moving from the Johansen procedure to single-equation methods, these results call into question the conclusion that foreign firms began to behave in a different manner when the dollar began its long appreciation.

The question remains, given the finding of two co-integrating vectors by the Johansen procedure, whether the E-G procedure was an appropriate simplification. Further light can be cast on this problem by re-estimating (29) four times, using each of the four variables in turn as the dependent variable. The resulting four estimates of a single co-integrating vector can then compared by dividing each vector by a constant such that the coefficient on pm is set equal to -1 (i.e. moved to the left-hand side). The four estimates of the single co-integrating vector are

	Dependent Variable			
Variable	pm	er	cf	pd
pm	-1.000	-1.000	-1.000	-1.000
er	-.586	-.663	-.660	-.477
cf	.652	.734	1.241	-.214
pd	.405	.330	-.133	1.246
constant	2.531	2.720	2.680	2.112

These results are not encouraging, particularly with respect to cf and pd, which switch sign across the different dependent variables. It is interesting how the coefficients from the vector that treats pd as the dependent variable correspond fairly closely to the coefficients from the vectors labelled b in Table 3. The sensitivity to the choice of normalization re-enforces the presumption of two co-integrating vectors.

IV. Traditional Specification

Further light can be shed on the stability of the pass-through relationship by comparing the E-G results to previous work. An estimated equation from H-M will be used as a representative specification. This equation is fairly typical of previous work in its use of PDLs and AR(1) corrections[15]. They estimated the following equation

$$\text{(32)} \quad pm = b_0 + \sum_{i=0}^{7} b_{i+1} er_{t-i} + \sum_{i=0}^{3} b_{i+9} cf_{t-i} + \sum_{i=0}^{8} b_{i+13} pd_{t-i} + b_{22} cu$$

$R^2 = .999$, $\sigma = .0067023$, DW = 1.768

RSS = .0018417 for 22 variables and 53 observations (75:2-88:2).

with the coefficients and standard errors

	Estimate	T-Ratio		Estimate	T-Ratio
b_o	3.2395	11.668	b_{12}	.16535	2.1005
b_1	-.21657	-8.077	b_{13}	.79902	3.8538
b_2	-.14935	-15.808	b_{14}	.067019	.4922
b_3	-.095155	-8.227	b_{15}	-.077009	-1.0278
b_4	-.053993	-3.1109	b_{16}	-.16633	-3.6853
b_5	-.025859	-1.4626	b_{17}	-.20093	-4.4736
b_6	-.010755	-.84742	b_{18}	-.18083	-3.9537

15. The purpose of the H-M paper was to "update" the pass-through analysis, hence they chose a PDL, AR(1) specification to facilitate comparison to previous work. Only their most general specification will be considered here (their equation (12), as the restrictions imposed by two other equations are rejected. Baldwin's equations are similar, he corrects for MA(4) errors.

b_7	-.0086791	-.82027	b_{19}	-.10602	-3.1618
b_8	-.019632	-.74058	b_{20}	.023504	1.3437
b_9	.071963	.89686	b_{21}	.20774	3.6981
b_{10}	.12132	2.3037	b_{22}	-.0066744	-.109
b_{11}	.15245	2.6393	rho	.42026	3.3718

The equation is corrected for first order serial correlation, and the distributed lags on cf and er are estimated as second-order PDLs. The distributed lag on pd places no constraint on the contemporaneous coefficient and a second-order PDL on the remaining coefficients.

Recursive estimation of (32) generated Charts 14-16. Chart 14 plots the break-point Chow tests for structural stability, while Charts 15 and 16 plot the short-run and long-run pass through coefficients as well as their standard errors. Chart 14 indicates structural instability when comparing periods through 1981 with later periods. Charts 15 and 16 indicate an approximately 50 percent reduction in absolute size of both the short-run and long-run elasticities during 1981. This instability is not unique to the H-M equation, as H-M state "On balance, the literature seems to support structural breaks in both the import price equation and the pass-through coefficient in the early 1980s. Our own results on this point are mixed."[16] Previous work has attributed such shifts to changes in foreign firm behavior due to the large appreciation of the dollar that began in roughly 1981.

It is surprising that the H-M equation shows problems with structural breaks, while (31) doesn't. Changes in the correlations between the explanatory variables in (31) and (32) can be used to pinpoint the cause of the instability in (32). To this end, correlations for these

16. Hooper and Mann p. 320. See also Piggot and Reinhart, Baldwin, and Mastropasqua and Vona (1988).

two sets of variables were calculated over the periods 75:2-80:4 and 82:1-88:2. The biggest change in correlation over the two periods was between the PDL, serial correlation corrected pd in (32) and Δpd from (31). This change in correlation suggests that the use of the PDL and the correction for serial correlation perhaps obscured the fundamental change that took place in domestic prices around 1981, muting the influence of domestic prices on import prices. The change is probably the result of the change in monetary policy operations begun in October 1979. This misspecification, brought about by inappropriate data transformations,[17] is a likely cause of the instability exhibited by (32), rather than a change in behavior of economic agents in response to the large dollar appreciation.[18] Unfortunately, the appropriate alternative specification is still not clear given the troubling instability of the Johansen procedure.

V. Conclusions

This paper makes two points. First, pass-through at the macroeconomic level is a complicated amalgamation of disparate industrial structures that involves more than one long-run equilibrium relationship between the variables of interest. The data are inconsistent with the three over-simplified models considered here. Efforts to relate the pass-through coefficient to parameters from a theoretical model are best done at as disaggregated a level as possible. Second, claims of changes in the aggregate behavior of economic agents in light of the large dollar appreciation appear to be unfounded.

17. Tests of the common factor restriction imposed by the serial correlation correction in equation (30) fail.
18. H-M are careful not to make this claim.

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APPENDIX I - Simple Example

Consider the relationship between the price of crude oil (C), heating oil (H), and gasoline (G). One might conjecture that the price of crude oil follows a random walk, and that in the long-run the prices of heating oil and gasoline move one-for-one with the price of crude oil. This system would possess two co-integrating vectors, subtracting H from C, and G from C (or equivalently G from H) would generate two I(0) combinations of I(1) variables. Such a system might have the following dynamic representation

$$
\begin{aligned}
C_t &= C_{t-1} && && + \epsilon_{1t} \\
H_t &= .07C_{t-1} + .03C_{t-2} + .5H_{t-1} + .4H_{t-2} && && + \epsilon_{2t} \\
G_t &= .14C_{t-1} + .06C_{t-2} && + .3G_{t-1} + .5G_{t-2} && + \epsilon_{3t}
\end{aligned}
$$

This can be written as

$$
\begin{array}{ccccccc}
\Delta X_t & = & \Gamma_1 \Delta X_{t-1} & + & \Pi X_{t-2} & + & \epsilon_t, \\
\begin{bmatrix} \Delta C_t \\ \Delta H_t \\ \Delta G_t \end{bmatrix} & = & \begin{bmatrix} 0 & 0 & 0 \\ .07 & -.5 & 0 \\ .14 & 0 & -.7 \end{bmatrix} \begin{bmatrix} \Delta C_{t-1} \\ \Delta H_{t-1} \\ \Delta G_{t-1} \end{bmatrix} & + & \begin{bmatrix} 0 & 0 & 0 \\ .1 & -.1 & 0 \\ .2 & 0 & -.2 \end{bmatrix} \begin{bmatrix} C_{t-2} \\ H_{t-2} \\ G_{t-2} \end{bmatrix} & + & \begin{bmatrix} \epsilon_{1t} \\ \epsilon_{2t} \\ \epsilon_{3t} \end{bmatrix}
\end{array}
$$

One arbitrary decomposition of Π would be

$$
\begin{array}{ccccc}
\alpha & & \beta' & & \Pi \\
\begin{bmatrix} 0 & 0 \\ -.1 & 0 \\ 0 & -.2 \end{bmatrix} & & \begin{bmatrix} -1 & 1 & 0 \\ -1 & 0 & 1 \end{bmatrix} & = & \begin{bmatrix} 0 & 0 & 0 \\ .1 & -.1 & 0 \\ .2 & 0 & -.2 \end{bmatrix}
\end{array}
$$

However, Π could also be decomposed as

$$\underset{\alpha}{\begin{bmatrix} 0 & 0 \\ -.1 & -.1 \\ -.4 & -.8 \end{bmatrix}} \underset{\beta'}{\begin{bmatrix} -1.5 & 2 & -.5 \\ .5 & -1 & .5 \end{bmatrix}} = \underset{\Pi}{\begin{bmatrix} 0 & 0 & 0 \\ .1 & -.1 & 0 \\ .2 & 0 & -.2 \end{bmatrix}}$$

generating a very different looking estimate of β. Normalizing the two estimates of β so that the first coefficient in each column equals -1 (as in the text) would give

$$\begin{bmatrix} -1 & -1 \\ 1 & 0 \\ 0 & 1 \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} -1 & -1 \\ 1.33 & 2 \\ -.33 & -1 \end{bmatrix}$$

In this system, the only restriction that can be imposed across the rows of <u>both</u> columns of β is $b_3 = -(b_1+b_2)$.

Appendix II - Data

The following brief data descriptions are for the most part taken directly from H-M:

PM = Fixed-weighted average (using 1982 imports share weights) of import prices for capital goods, automotive products, consumer goods, and industrial supplies excluding petroleum and products.

PD = Weighted average of producer price indexes for various manufacturing sectors weighted by shares in U.S. imports.

CD = Weighted average of manufacturing unit labor costs and the producer price index for crude materials for further processing.

The foreign variables were constructed using nine countries that comprise approximately 75 percent of non-oil manufactured imports.[19]

ER = Weighted average of foreign exchange rates, using variable current-import-share weights.

CF = Variable current-import-share weighted average of individual country costs. For each country a weighted average of unit labor compensation in manufacturing and price indexes for raw material and energy inputs into manufacturing was constructed. The weights used were .65 for labor and .35 for materials and energy.

CU = Weighted average of foreign capacity utilization rates using variable current-import-share weights.

19. The countries were Canada, United Kingdom, West Germany, France, Italy, Japan, Korea, Taiwan, and Mexico.

APPENDIX III - Stationarity Tests

Table A.1 presents six stationarity tests (corresponding to the six columns) for each variable and its first difference. Test statistics for six null hypotheses concerning the parameter γ_2 from the regression

$$\text{(A.1)} \quad x_t = \gamma_0 + \gamma_1 t + \gamma_2 x_{t-1} + \gamma_3 \sum_{j=1}^{t} .95^{j-1} + \sum_{i=0}^{n} i*\phi_i (x_{t-i} - \gamma_4 x_{t-i-1})$$

are presented, where x is the natural logarithm of the variable of interest (e.g. pm = ln(PM)). The familiar Dickey-Fuller (DF) and augmented Dickey-Fuller (ADF) tests of the null hypothesis $\gamma_2 = 1$ are displayed in columns 1, 2, 4, and 5. As an alternative, the DeJong, Nankervis, Savin, and Whiteman (1989) (DNSW) test of the null hypothesis $\gamma_2 = .95$ is displayed in column 3, and an augmented DNSW (ADNSW) test is shown in column 6.[20] Below each test statistic is an LM test of serial correlation up to the fourth order in the residuals of (A.1).

---

20. The DNSW paper does not present an augmented test although they do note that most macroeconomic time series display positive serial correlation that invalidates the test they propose. I constructed the ADNSW test in order to make inference in the presence of positive serial correlation. Critical values for this test were obtained by Monte Carlo methods using 5000 repetitions and 10 values of rho (0.0 through .9) for the model $x_t = z_t$, $z_t = .95 z_{t-1} + u_t$, $u_t = \theta u_{t-1} + \epsilon_t$.

One-sided critical values obtained for the values of rho were

θ	0.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
critical value	-.72	-.73	-.73	-.73	-.72	-.73	-.70	-.64	-.47	+.38

The critical value reported in the table was that for $\theta = .3$, the θ that fit most closely the six series used in the pass-through analysis.

Table A.1

	DF n=0 $\gamma_1=0,\gamma_3=0,\gamma_4=1$	DF n=0 $\gamma_3=0,\gamma_4=1$	NSDW n=0 $\gamma_4=.95$	ADF n=1 $\gamma_1=0,\gamma_3=0,\gamma_4=1$	ADF n=1 $\gamma_3=0,\gamma_4=1$	ANSDW n=1 $\gamma_4=.95$
Ho:	$\gamma_2=1$	$\gamma_2=1$	$\gamma_2=.95$	$\gamma_2=1$	$\gamma_2=1$	$\gamma_2=.95$
pm						
T-stat	-4.894*	-3.405	.613*	-1.718	-2.085	-1.413
LM-sig	.000	.000	.000	.821	.927	.878
er						
T-stat	-.973	-.542	1.122*	-1.501	-1.148	-.161*
LM-sig	.023	.014	.054	.736	.679	.752
co						
T-stat	-5.381*	-2.426	-.152*	-2.910*	-2.229	-1.272
LM-sig	.024	.012	.002	.108	.193	.061
cu						
T-stat	-2.426	-1.920	-.693	-3.472*	-3.373	-2.947
LM-sig	.000	.000	.000	.870	.876	.926
pd						
T-stat	-6.560*	-1.037	.652*	-2.307	-1.641	-1.664
LM-sig	.000	.000	.000	.719	.700	.686
cd						
T-stat	4.897*	-0.763	.745*	-3.092	-0.648	0.101
LM-sig	.001	.002	.000	.003	.004	.001
Δpm						
T-stat	-3.807*	-3.763*	-3.458	-2.652	-2.673	-2.672
LM-sig	.861	.886	.033	.399	.424	.007
Δer						
T-stat	-5.255*	-5.319*	-4.974	-4.112*	-4.218*	-3.814
LM-sig	.871	.885	.590	.663	.788	.442
Δco						
T-stat	-4.091*	-4.804*	-4.570	-3.305*	-3.792*	-3.413
LM-sig	.081	.378	.017	.184	.394	.007
Δcu						
T-stat	-3.757*	-3.796*	-3.371	-3.807*	-3.889*	-3.517
LM-sig	.428	.189	.015	.568	.161	.024
Δpd						
T-stat	-2.498	-3.090	-2.572	-2.500	-3.441	-2.996
LM-sig	.591	.694	.108	.866	.580	.000
Δcd						
T-stat	-5.053	-6.300	-5.860	-3.301	-3.812	-3.339
LM-sig	.000	.007	.000	.000	.001	.000

*Statistically different from zero at the 5% signifigance level

Significant serial correlation makes inference impossible using the DF and DNSW tests for the levels of the variables. For the augmented tests the troubling but common result is that: 1) the ADF tests cannot reject the difference stationary (I(1)) hypothesis (with the exceptions of cf and cu when $\gamma_1=0$) and 2) the ADNSW test cannot reject the trend stationary (I(0)) hypothesis.[21] Tests based on the differences of the variables indicate that with the possible exception of pd and cd, none of the variables needs to be differenced more than once to be rendered stationary (i.e. none appear to be I(2)). In sum, no firm conclusion regarding the stationarity of the univariate process for each variable can be reached. However, this result is not as troubling as might first appear. The issue to be examined here is the process for pm conditional on the remaining variables. Keeping this in mind, the results in Table 1 indicate the importance of flexible estimation strategies, such as the Johansen procedure, that allow for I(1) variables.

21. Although the ADF(1) tests for cd continue to display significant serial correlation, the residuals for an ADF(5) do not and the difference stationary hypothesis cannot be rejected for the ADF(5). However, augmenting the DNSW test with as many as six lags was not successful in eliminating the serial correlation.

Chart 1
pm

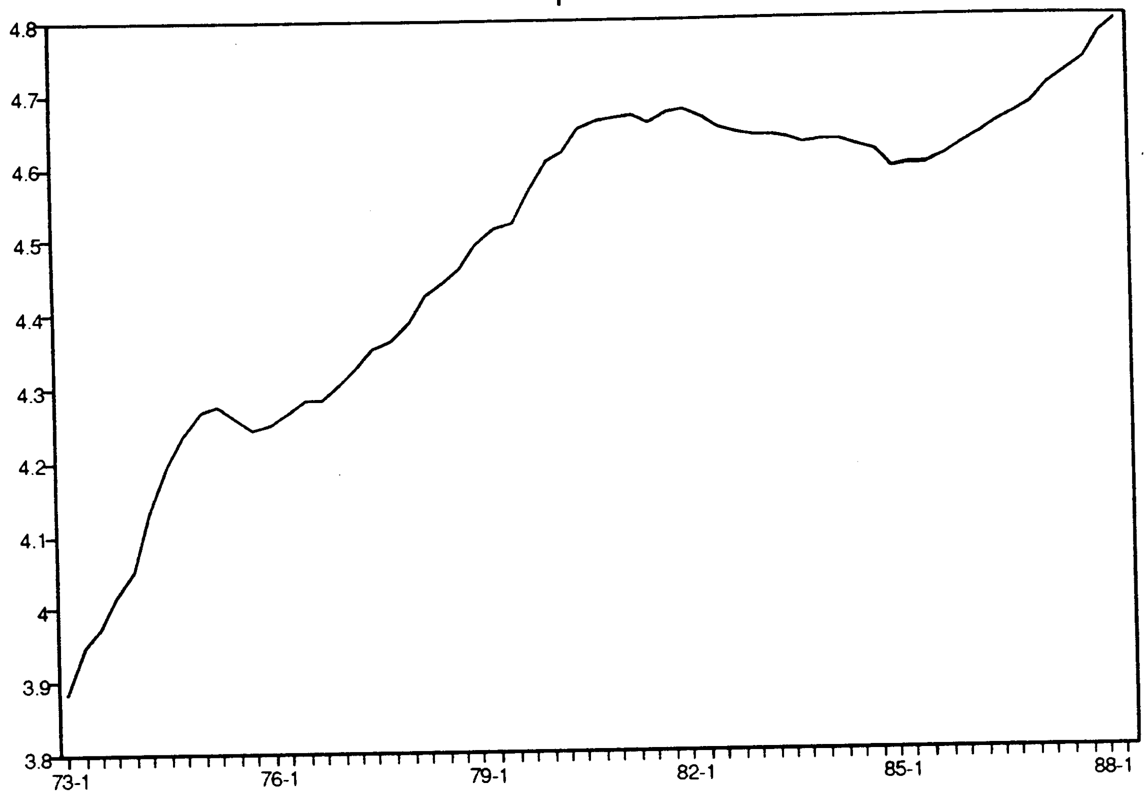


Chart 2
er

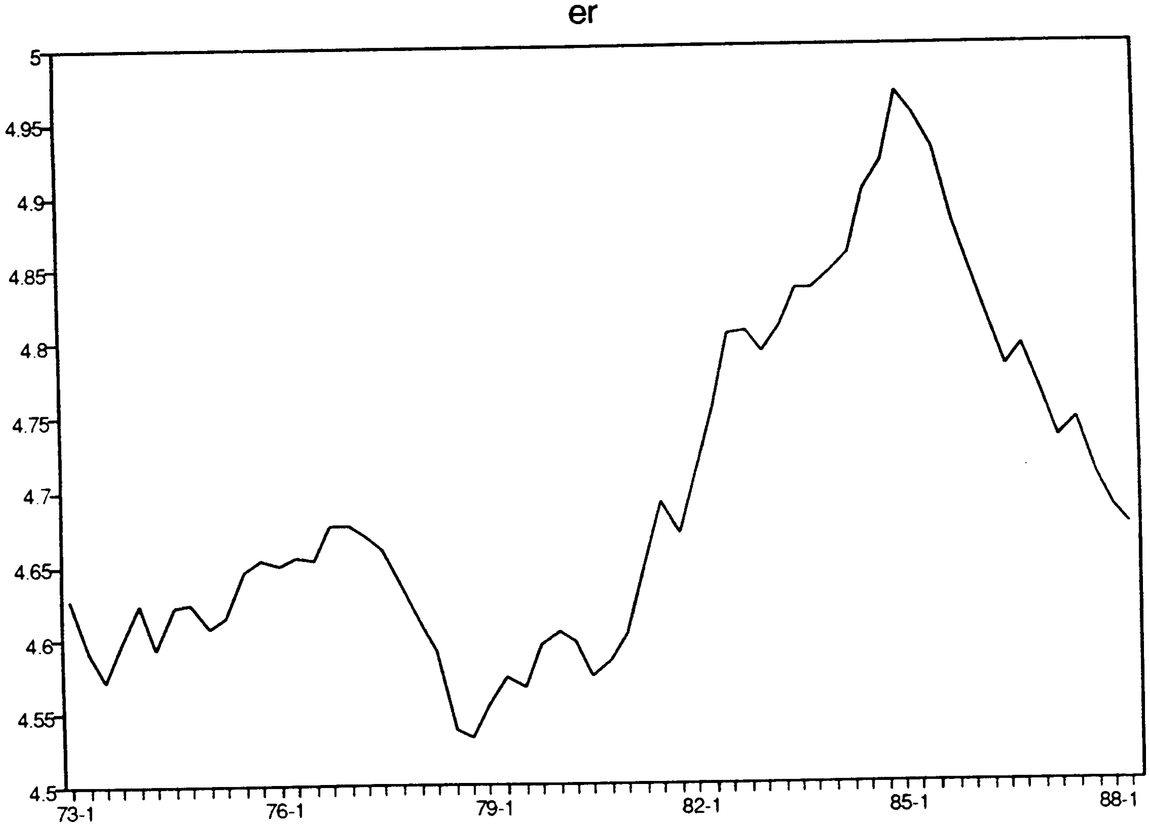


Chart 3

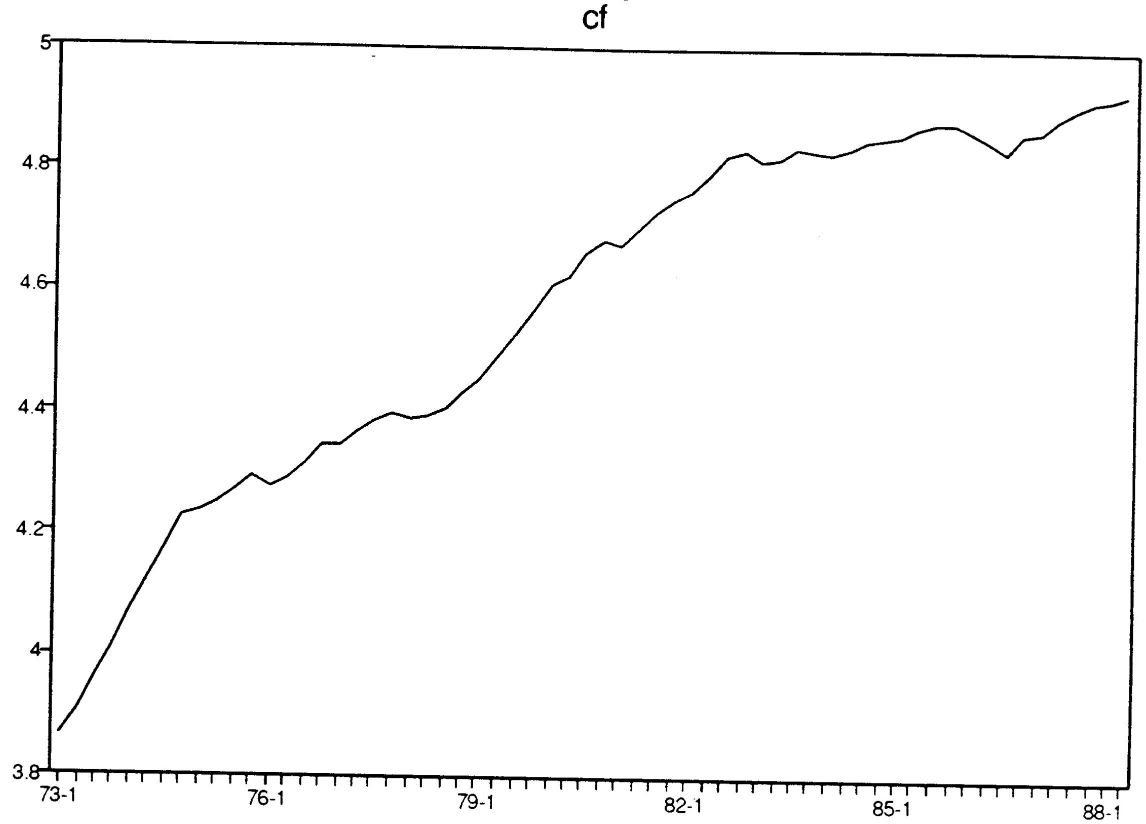


Chart 4

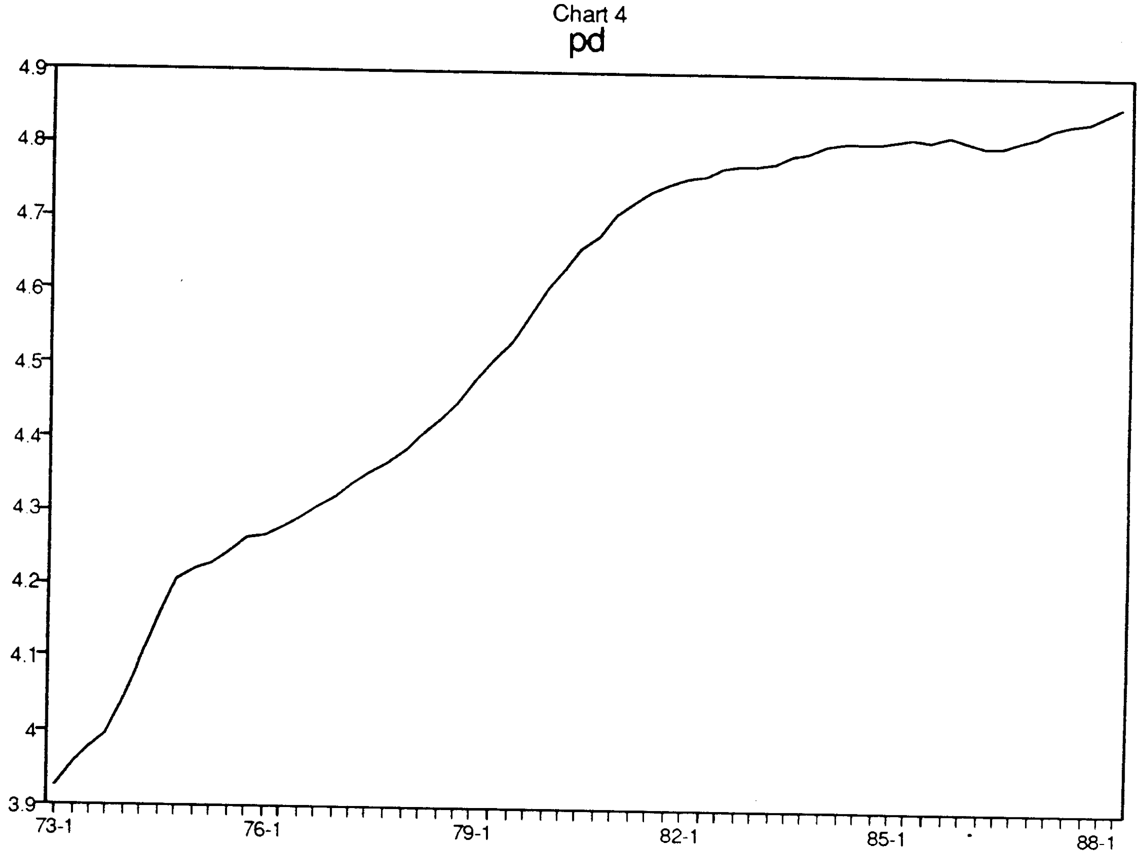


Chart 5
cd

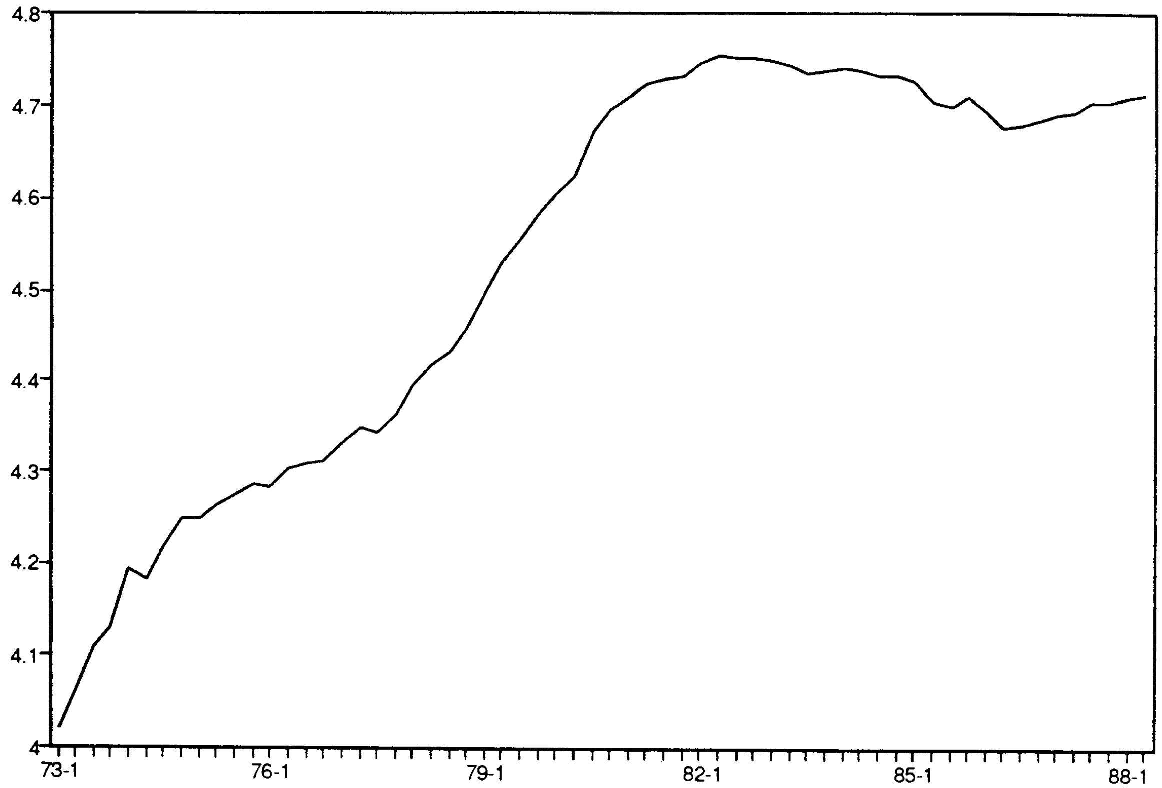


Chart 6
Break-Point Chow, pm in VAR eq. (16)

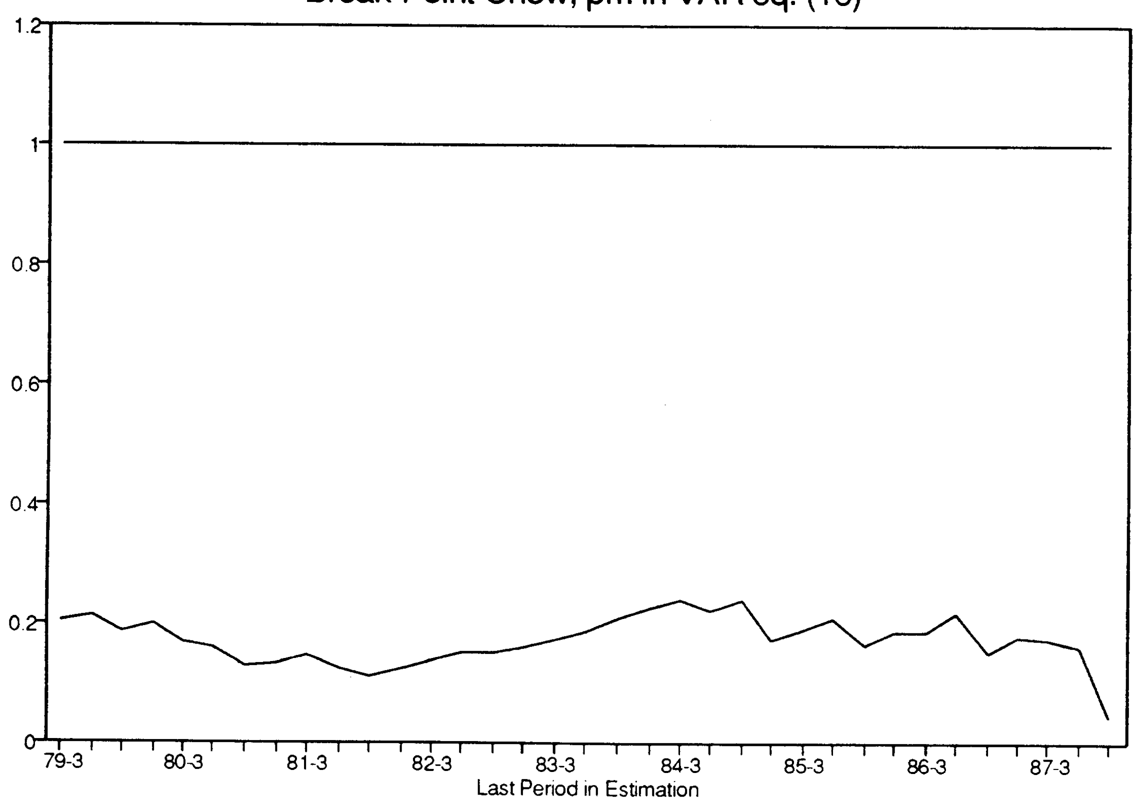


Chart 7
Break-Point Chow, er in VAR eq. (16)

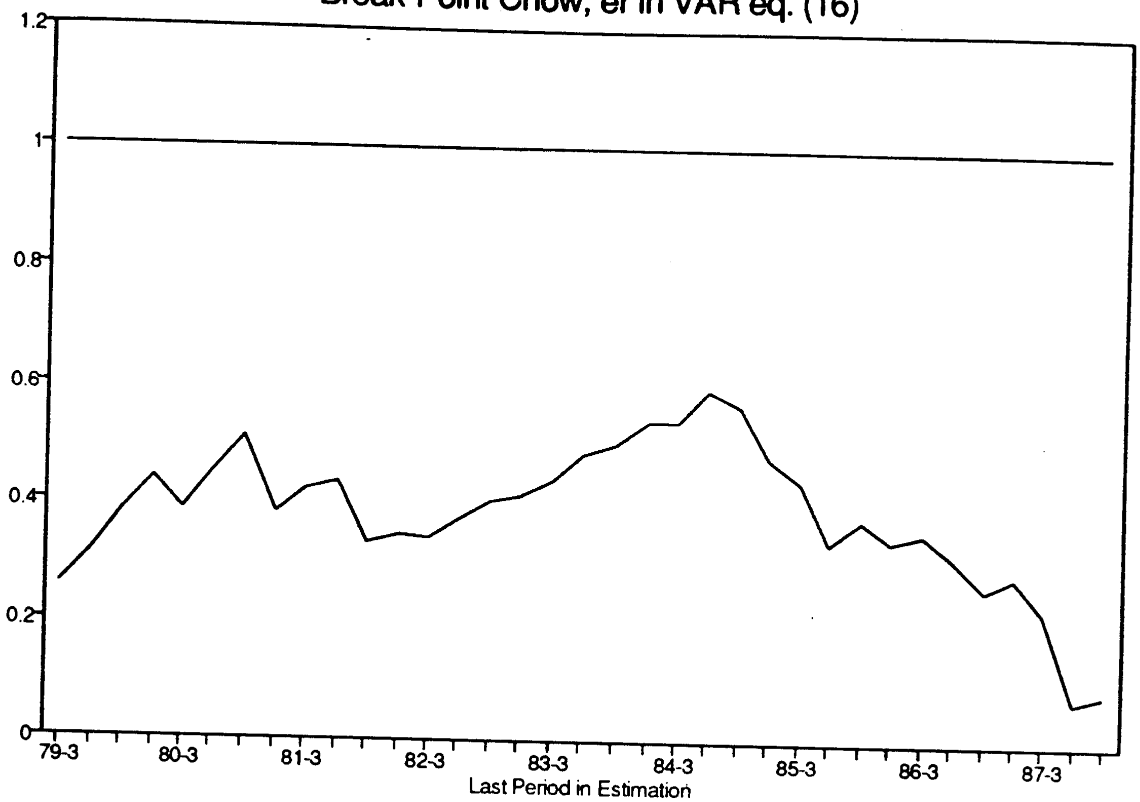


Chart 8
Break-Point Chow, cf in VAR eq. (16)

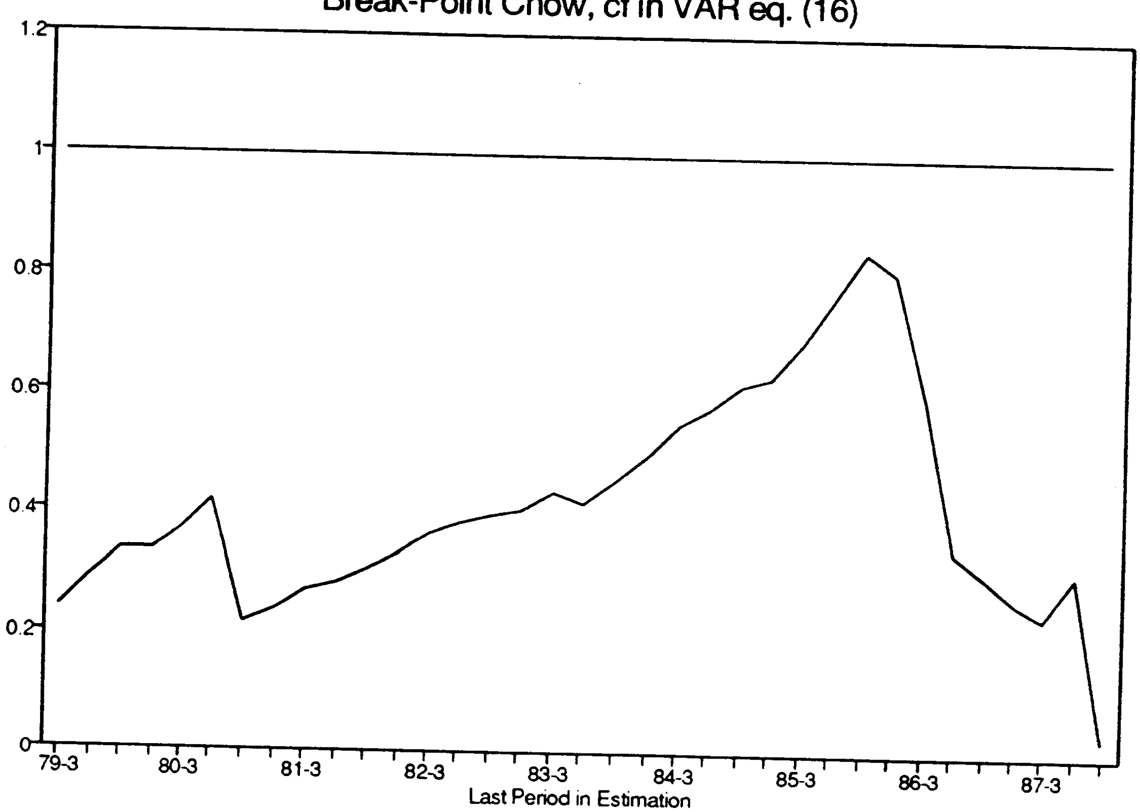


Chart 9
Break-Point Chow, pd in VAR eq. (16)

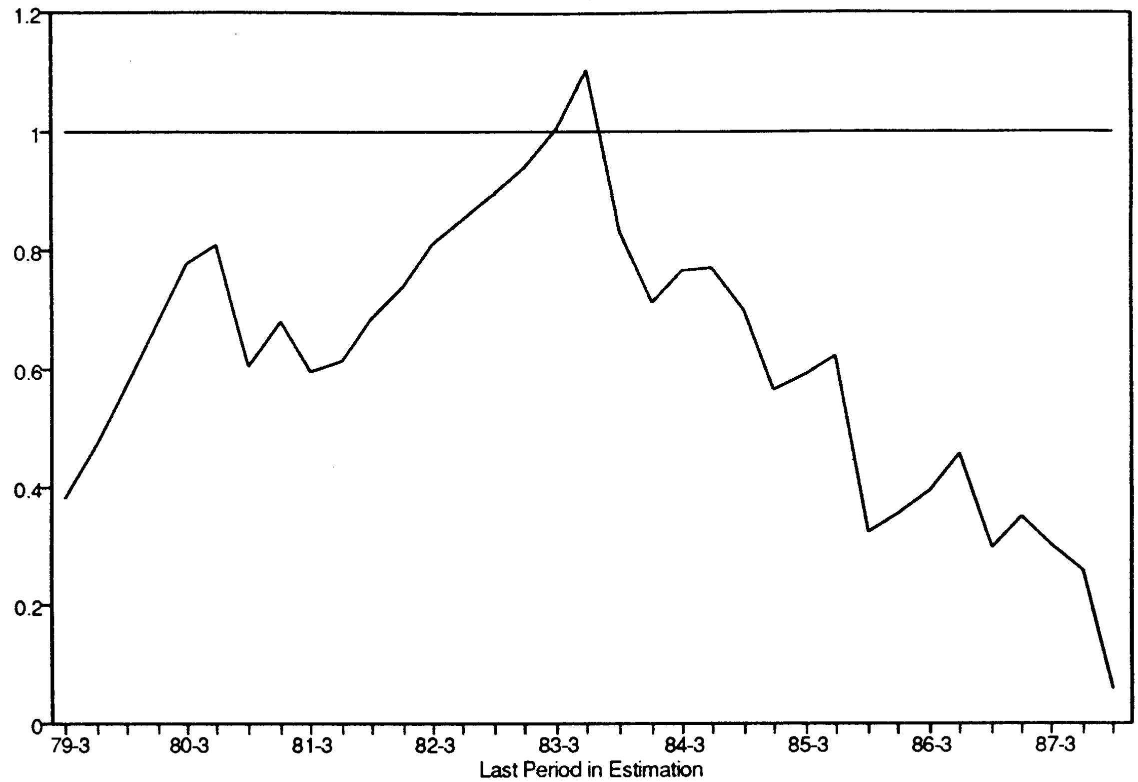


Chart 10
Coefficient on LER, Average

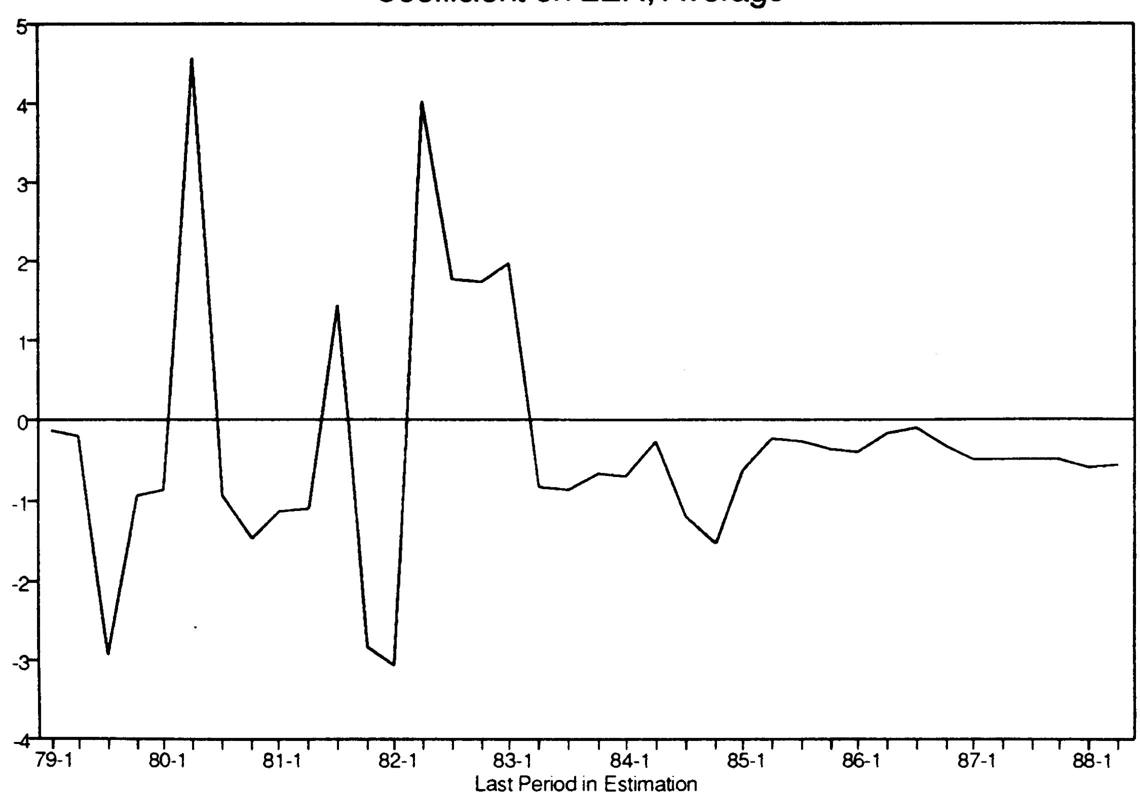


Chart 11
Break-Point Chow, eq. (31)

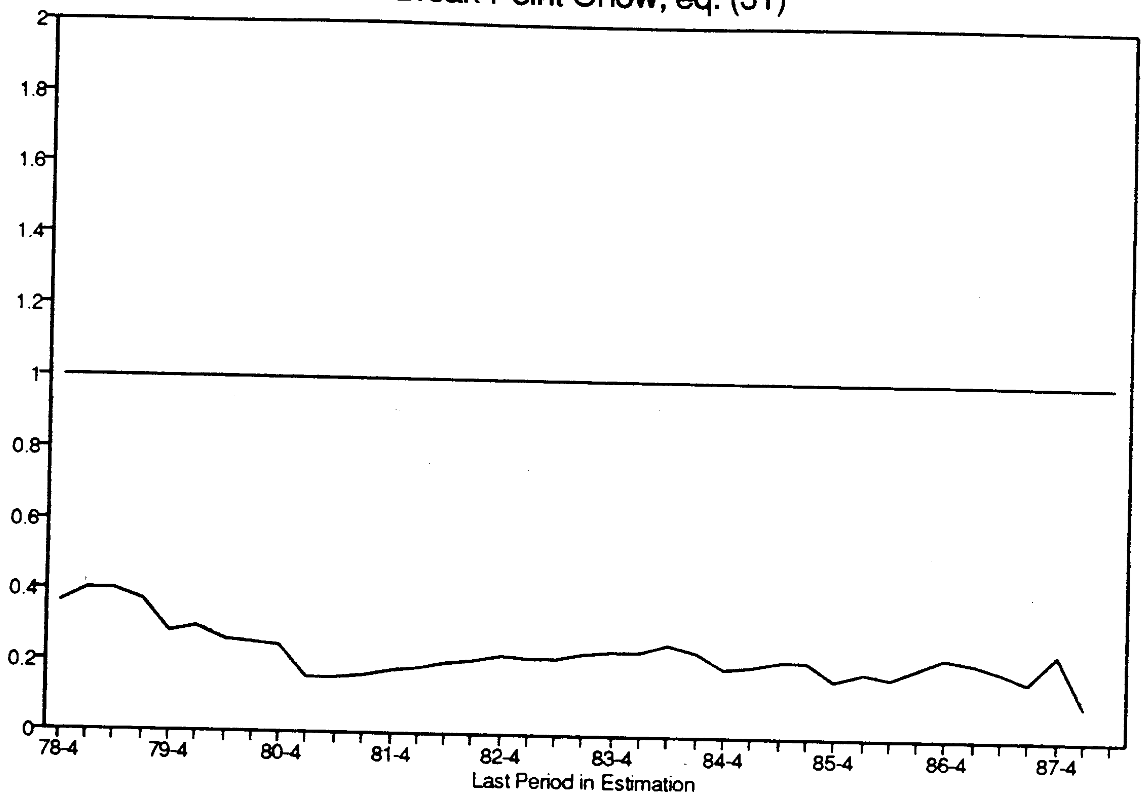


Chart 12
Coefficient on ECM +/- 2 S.E. eq. (31)

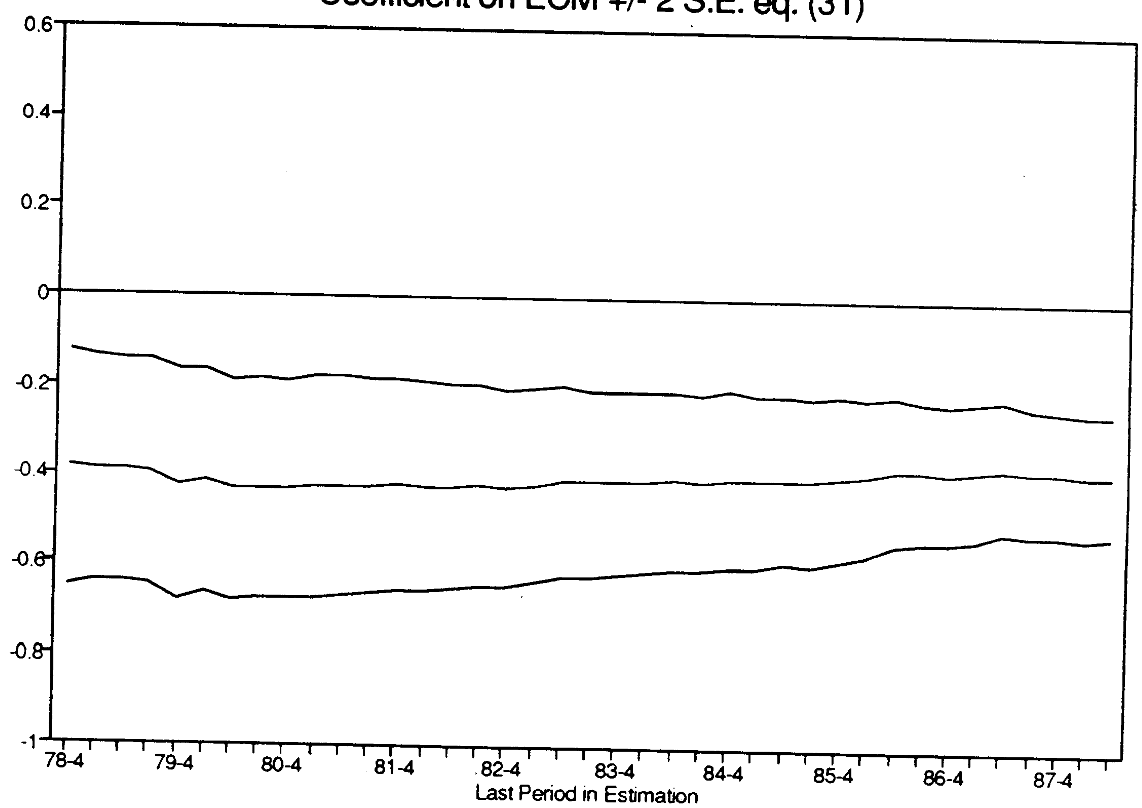


Chart 13
Coefficient on er +/- 2 S.E. eq.(31)

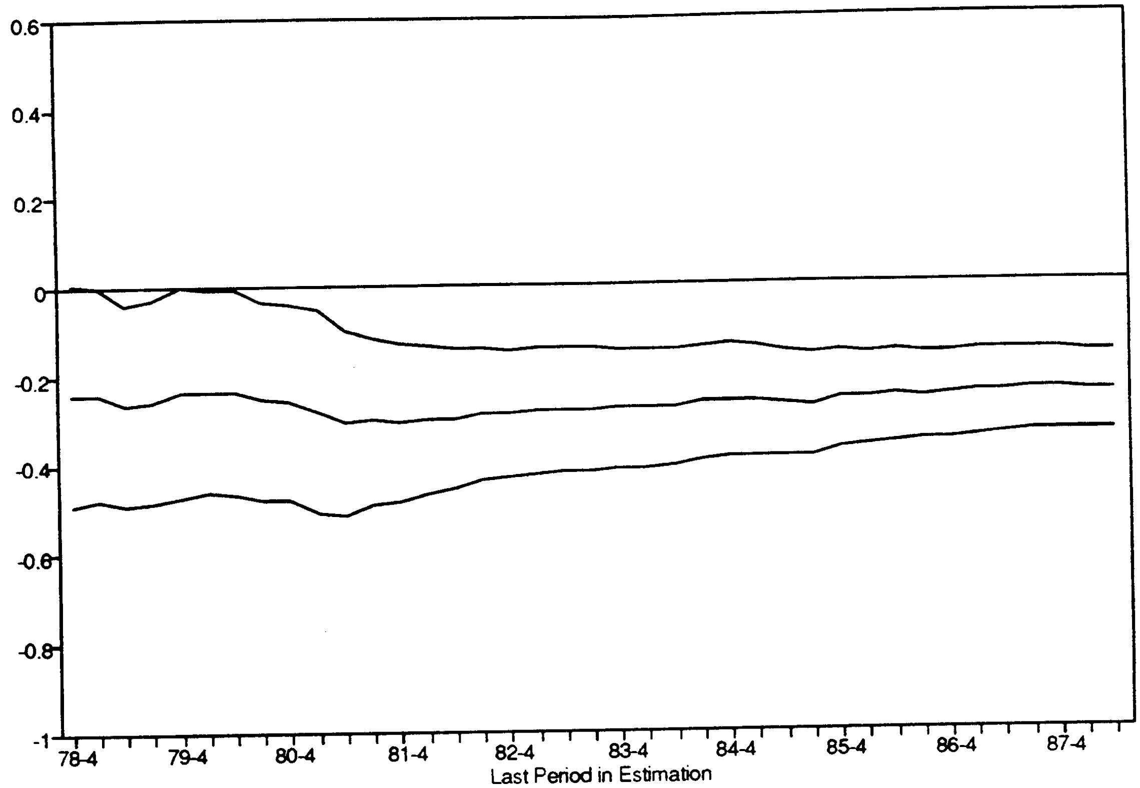


Chart 14
Break-Point Chow, eq. (32)

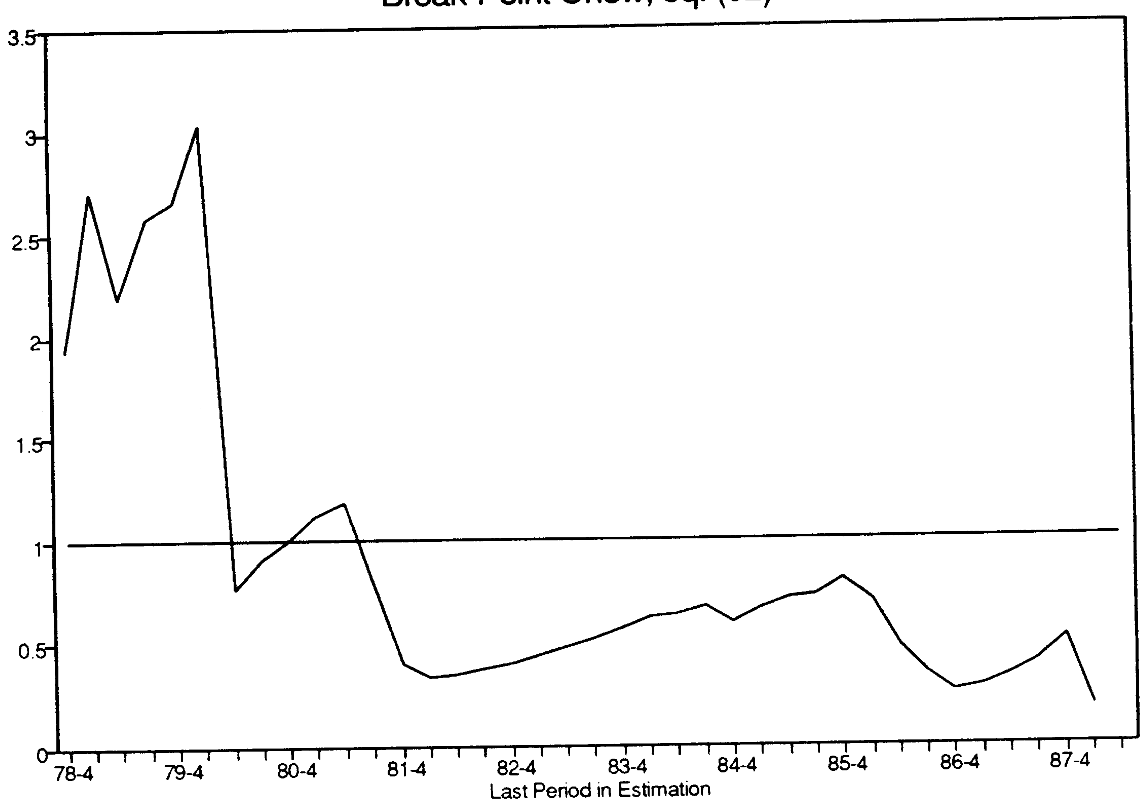


Chart 15
S-R Coefficient on er eq. (32)

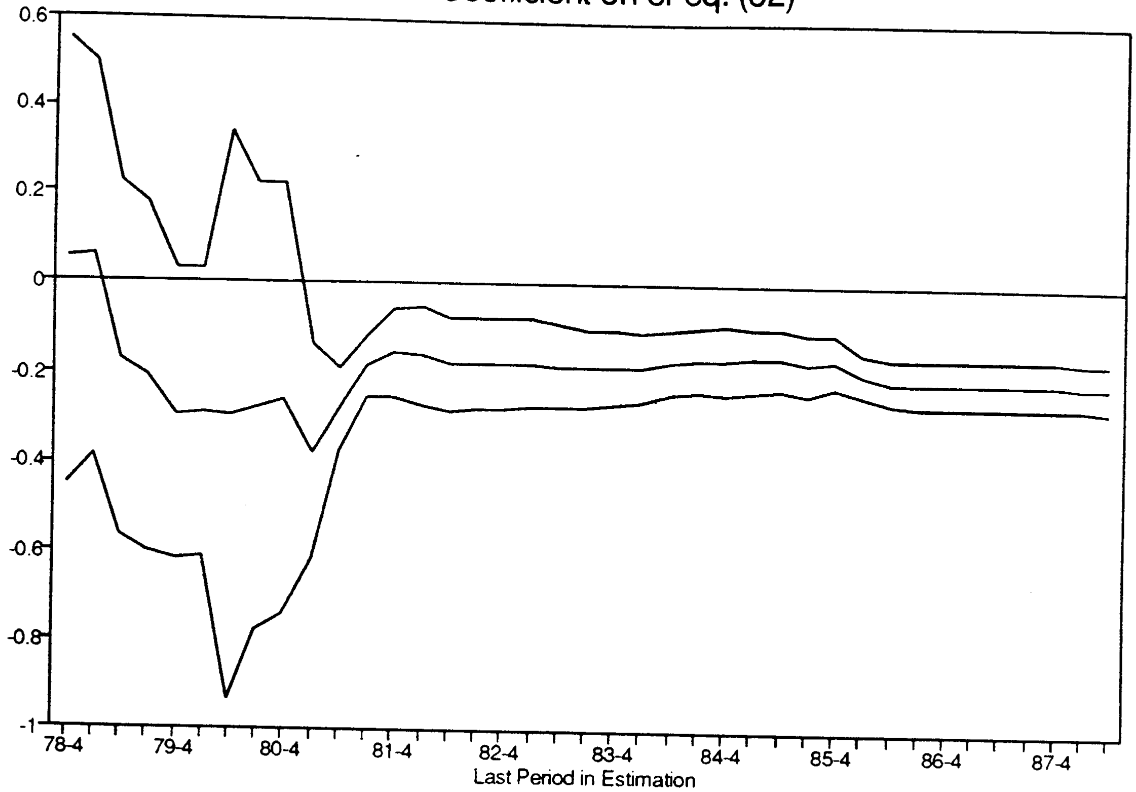
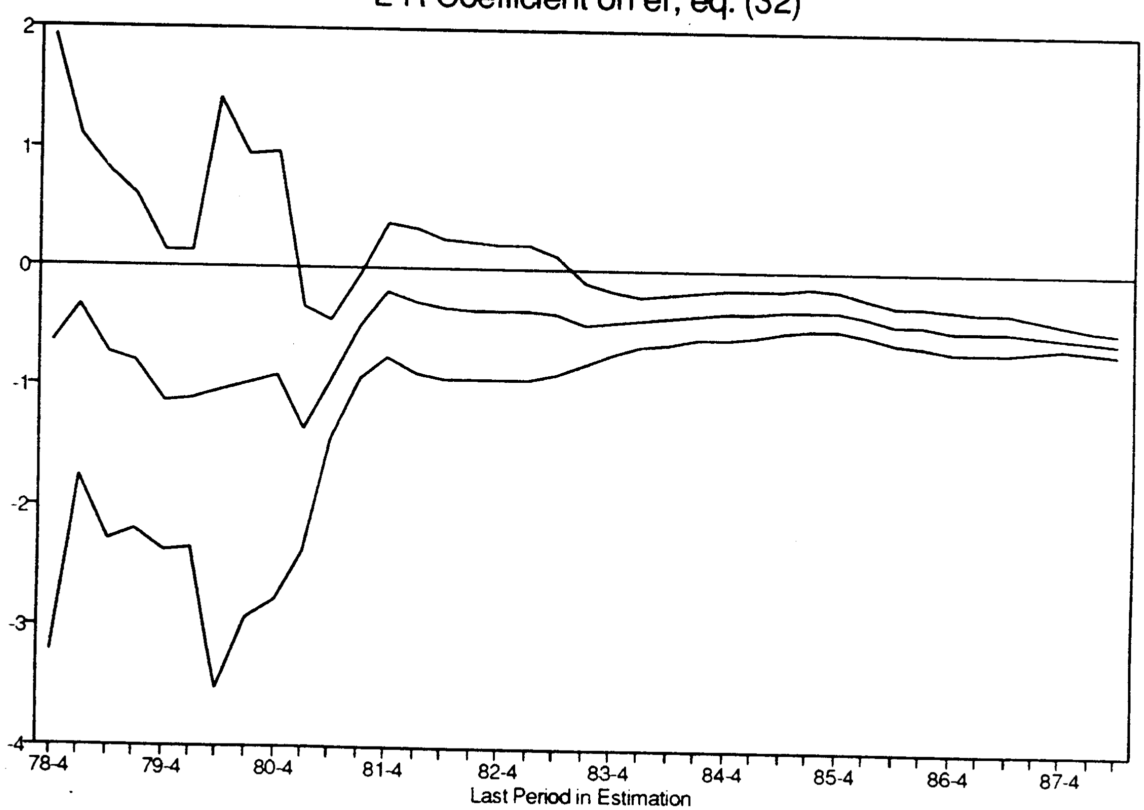


Chart 16
L-R Coefficient on er, eq. (32)



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