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Aggregate Exchange Rate Pass-Through: Instability and Inference

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Abstract

The instability displayed by aggregate, econometric specifications of pass-through has been cited as evidence in favor of theoretical models of pass-through that allow for hysteresis. This paper argues that 1) An unstable econometric specification should not be used as evidence in favor of a theoretical model, and 2) Aggregate models of pass-through are very uninformative, given the different market structures that are likely to be aggregated.

I. Introduction

Many econometric equations that explain the pass-through of dollar exchange rate changes into aggregate U.S. import prices displayed structural instability during the 1980's. This instability has been cited as evidence supporting theoretical models of industry pricing behavior that allow a temporary change in the exchange rate to have a permanent effect on price (*i.e.*

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hysteresis). Baldwin [1988] is perhaps the most prominent example of research that relies on instability for indirect verification.[1] He writes:

> "The evidence in this section does not directly test the model. It is simply intended to establish 1) that the historical relationship between the exchange rate and U.S. aggregate, non-oil import prices has shifted in the 1980s, and 2) that the nature of the shift is not inconsistent with the predictions of the model."

This paper resorts to a more mundane explanation for the instability of aggregate pass-through equations, namely misspecification. The paper makes two points. First, theoretical models of pricing behavior ought to draw support from industry-level studies (where market structure hypotheses can be verified) instead of from the instability of single-equation applications to aggregate data. Secondly, it is doubtful if aggregate studies of pass-through have any content at all. At the aggregate level, pass-through is likely to be a complicated amalgamation of many different market structures that is not well captured by specifications suggested by a single theoretical model. Section II presents three simple theoretical models of pass-through to guide the econometric work that follows. A "traditional" pass-through specification is re-estimated in section III to document the 1980s instability found in the studies mentioned above. Section IV presents results from an estimation technique that: 1) accommodates data that are possibly nonstationary, and 2) provides a means to test the long-run implications of the theories presented in section II. The results from section IV do not display instability, but the restrictions implicit in each of the theoretical models are all rejected. Conclusions are reached in section V.

II. 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, Feenstra [1989], Marston [1990], Hooper and Mann, Baldwin, and Dornbusch

1. There are others. For example, Hooper and Mann [1989], in a pass-through survey paper, conclude "On balance, the literature seems to support structural breaks in o-th the import price equation and the pass-through coefficient in the early 1980s. Our own results on this point are mixed."

[1987]. A typical specification can be written as

$$PM = f(ER, PD, CF, CD) \tag{1}$$

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 should hold. These three conditions can be written as

$$\frac{PD}{CD} = 1 + r^d \tag{2}$$

$$\frac{PM \cdot ER}{CF} = 1 + r^f \tag{3}$$

$$\frac{PM}{PD} = 1 \tag{4}$$

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,

$$CF = ER \cdot CD \tag{5}$$

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 firm, 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

$$Q_f = -a_1 \cdot PM + b_1 \cdot PD \qquad a_1, b_1 > 0 \tag{6}$$

$$Q_d = b_2 \cdot PM - a_2 \cdot PD \qquad a_2, b_2 > 0 \tag{7}$$

Profits for the two firms would then be given by

$$\Pi_f = (-a_1 \cdot PM + b_1 \cdot PD) \cdot (PM \cdot ER - CF) \tag{8}$$

$$\Pi_d = (b_2 \cdot PM - a_2 \cdot PD) \cdot (PD - CD) \tag{9}$$

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]

$$PM = \frac{2 \cdot a_2}{4 \cdot a_1 \cdot a_2 - b_1 \cdot b_2} \cdot \left(\frac{b_1 \cdot CD}{2} + \frac{a_1 \cdot CF}{ER} \right) \tag{10}$$

$$PD = \frac{2 \cdot a_1}{4 \cdot a_1 \cdot a_2 - b_1 \cdot b_2} \cdot \left(\frac{b_2 \cdot CF}{2 \cdot ER} + a_2 \cdot CD \right) \tag{11}$$

The mark-up model of Hooper and Mann is a second imperfectly competitive formulation. The mark-up of price over cost is given by

$$PM = \gamma \cdot \frac{CF}{ER} \tag{12}$$

The mark-up, γ, 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

$$PM = \left(\left(\frac{PD \cdot ER}{CF} \right)^{\sigma} \cdot CU^{\delta} \right) \cdot \frac{CF}{ER} \tag{13}$$

Polar cases can be considered. Setting σ equal to 1 and δ equal to zero transforms (13) into the purchasing power parity condition found in (4) of the perfectly competitive model. Exchange rates have no effect on import prices. Setting σ and δ equal to zero yields complete pass-through as exchange rate changes are entirely offset.

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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.

The remaining sections of the paper try to analyze aggregate data in the light of three models just presented. However, even for a particular market (given no prior knowledge of its industrial structure) it is not apparent which of the three models would provide the best theoretical approximation to reality. The situation is even more complicated for aggregate data, making the choice of the "correct" theoretical specification hopeless. The traditional application of the Hooper-Mann model is presented in section III, while section IV tries each of the three models in turn, using a more appropriate econometric technique.

III. Traditional Specification

An estimated equation from Hooper and Mann will be used as a representative specification that exhibits instability in the 1980s. Importantly, this equation is fairly typical of previous work in its use of PDLs and AR(1) corrections.[3] The quarterly data set found in Hooper and Mann, augmented with the domestic cost variable *CD*, is used throughout this paper. The data set contains 62 observations, beginning in the first quarter of 1973 (73:1) and ending in the second quarter of 1988 (88:2) (see the Data Appendix for details). Hooper and Mann estimated the following equation which is a log-linear version of (13) (lower case letters denote variables expressed as natural logarithms)

$$pm = c_0 + \sum_{i=0}^{7} c_{i+1} \cdot er_{t-i} + \sum_{i=0}^{3} c_{i+9} \cdot ef_{t-i} + \sum_{i=0}^{8} c_{i+13} \cdot pd_{t-i} + c_{22} \cdot cu \qquad (14)$$

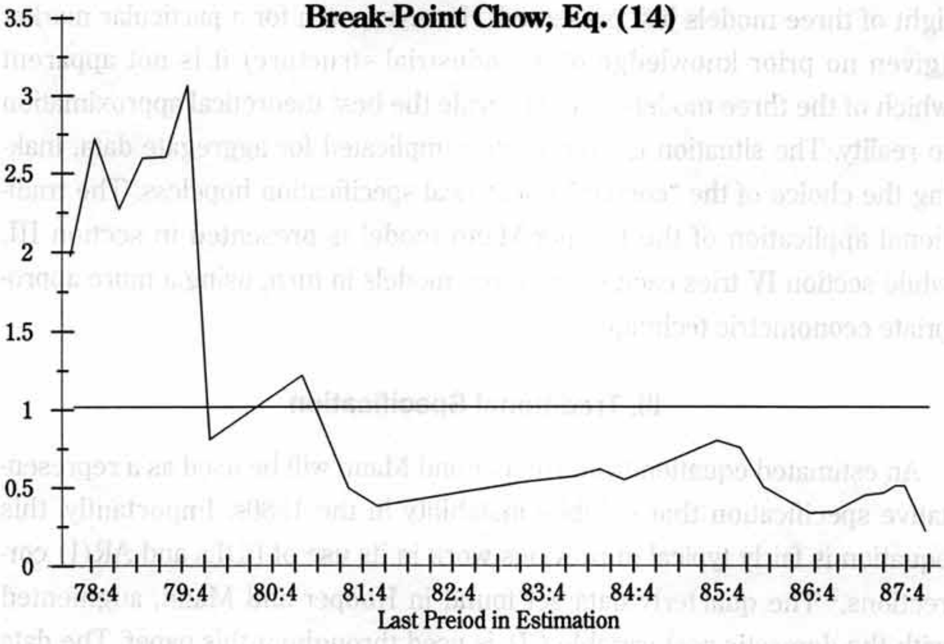
$R^2 = .999$, standard error of the estimate = .0067023, D.W. = 1.768,
RSS = 0018417, 53 observations (75:2 – 88:2)

with the coefficients and standard errors omitted to save space. 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

3. The purpose of the Hooper and Mann 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 specifications are rejected. Baldwin's equations are similar, he corrects for MA(4) errors.

Figure 1

Break-Point Chow, Eq. (14)



PDL on the remaining coefficients.

Recursive estimation of (14) generated Figure 1; which plots break-point Chow tests for structural stability, and indicates structural instability when comparing periods through 1981 with later periods.[4] As stated above, this instability is not unique to the Hooper and Mann equation (see also Piggot and Reinhart [1985], Baldwin, Mastropasqua and Vona [1989], Kim [1990] and Parsley [1993]).

The instability of the "traditional" equation might well be the result of misspecification rather than the behavioral shift predicted by a hysteresis model. There are two reasons to be skeptical of the specification of (14). First, the data might well be non-stationary; requiring special econometric

4. 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 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 is rejected.

treatment to avoid a spurious regression. Augmented Dickey-Fuller tests (including a trend term) on each of the series are unable to reject the null hypothesis of a unit root. However, to be even-handed, tests proposed by DeJong *et al.* [1992] are unable to reject the trend stationarity hypothesis for each of the series.[5] Secondly, the specification in (14) imposes several restrictions, most importantly the common factor restriction implicit in the serial correlation correction. In fact, the common factor restriction in (14) fails.[6] This misspecification, brought about by inappropriate data transformations, is as likely a cause of the equation's instability as is any of the behaviors predicted by the hysteresis models. The next section will demonstrate that a stable specification can be found, contrary to the predictions of the hysteresis models.

IV. Alternative Specification

The test results in section III, indicated the need for a non-restrictive estimation approach that can accommodate, if necessary, nonstationary data. The Johansen [1990] procedure meets these estimation requirements. The procedure analyzes the relationship among p I(1) or I(0) variables using the following VAR system

$$\Delta X_t = \Gamma_1 \cdot \Delta X_{t-1} + \ldots + \Gamma_{k-1} \cdot \Delta X_{t-(k-1)} - \Pi \cdot X_{t-k} + \mu + \eta \cdot D_t + \varepsilon_t \quad (15)$$

where X_t is a $(p, 1)$ vector of observations on the p variables at time t. D_t is a $(3, 1)$ matrix of centered, seasonal, dummy variables,[7] μ is a $(p, 1)$ vector of constant terms for each equation, and ε_t is a $(p, 1)$ vector of error terms. The matrices Γ, and Π are (p, p) matrices of coefficients, and η is a $(p, 3)$ matrix of coefficients.

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5. Due to space considerations, these stationarity test results are not displayed. See Melick [1990] for the detailed results.
6. This is true whether or not the distributed lags are forced to lie on a polynomial. Without PDLs, an F-test of the common factor restriction yields a test statistic of 2.84 compared to the critical value of 2.76 (5% level of significance). With the PDLs, an F-test of the common factor restriction yields a test statistic of 3.24 compared to the critical value of 2.63.
7. A centered, seasonal dummy variable sums to zero over a year's time.

The theories in section III focused on equilibrium relationships, those that would be evident over a relatively long horizon. Within the Johansen procedure, these relationships should be captured in the Π matrix. There are three possibilities:

1. Rank of $\Pi = p$. All of the variables in X are I(0), no special econometric methods are needed to handle non-stationarity
2. Rank of $\Pi = 0$. Π is the null matrix, ΔX is I(0), there are no equilibrium relationships
3. Rank of $\Pi = r < p$. There are r linear combinations of ΔX that are I(0), r equilibrium relationships.

If $0 < r < p$, then Π can be decomposed into two (p, r) matrices α and β such that

$$\Pi = \alpha \cdot \beta' \tag{16}$$

It is important to emphasize that these matrices are not unique. The matrix β consists of the r $(p, 1)$ co-integrating vectors or equilibrium relationships[8] while α, termed the loadings by Johansen, are the coefficients on the cointegrating vector(s) in each of the p equations.

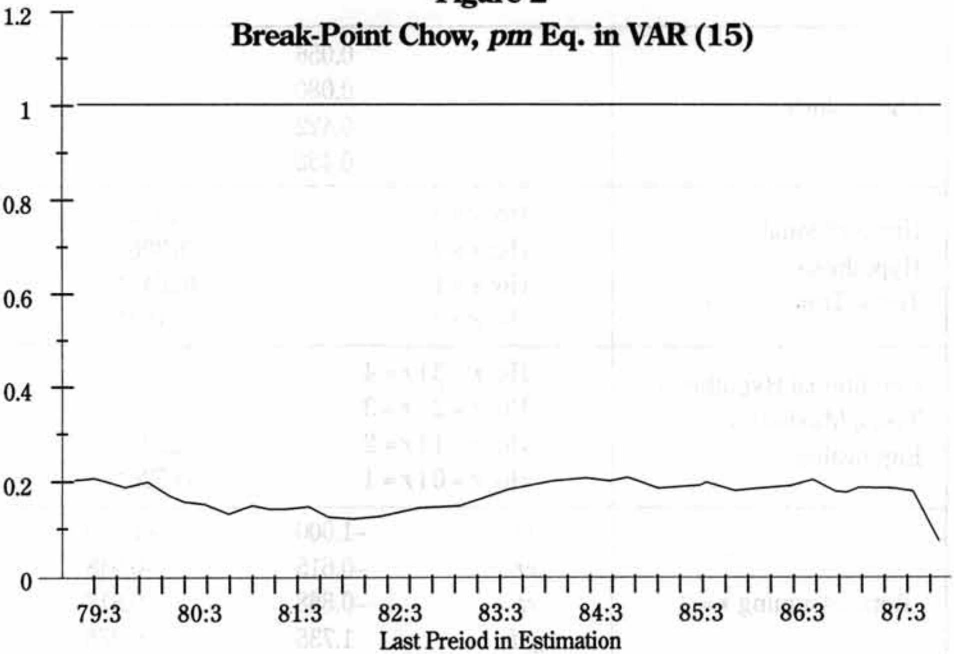
In order to implement the Johansen procedure one must choose a value for k, the number of lags in (15). Unfortunately the procedure can be sensitive to the choice of k. Box-Pierce Q-tests indicated that, for the systems studied, a lag length of 3 was sufficient to ensure white noise errors for each of the equations in (15). Lag lengths of 2 and 4 were also used, with little change in the results.[9]

The variables from the previous section's "traditional" specification were estimated with the Johansen procedure.[10] Recursive estimation of the Johansen procedure for the four variable system was used to calculate break-point Chow tests for the import price equation in (15). The tests are

8. Under certain conditions the constant terms in (15) can be incorporated in the cointegrating vectors, yielding cointegrating vectors of dimension $(p + 1, 1)$.
9. See Melick [1990] for the results with these lag lengths.
10. The capacity utilization variable used by Hooper and Mann is ignored here, as it never entered significantly in any of their results. For this system, test results indicated that a constant term could be included in the cointegrating vectors.

Figure 2

Break-Point Chow, *pm* Eq. in VAR (15)



illustrated in Figure 2. The import price equation exhibits no instability, in direct contrast to the predictions of the hysteresis models and the empirical results of earlier work.[11]

The full results of the Johansen procedure are presented in Table 1. The top half of Table 1 presents the estimated eigenvalues and the conditional and unconditional hypothesis tests that use these eigenvalues to determine the number of cointegrating vectors (*r*). Starred values indicate a rejection of the null hypothesis shown on the left-hand side of the table at the 5% significance level. Two significant cointegrating vectors are identified for the four variable system, regardless which of the tests is used. 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. The presence of two co-integrating vectors is not consistent with the Hooper-Mann markup model (equation (13)) which allows for only one long-run equilibrium

11. In fact, only the equation for *pd* in the VAR, equation (15), exhibits any instability, and then only for one period. Given the number of Chow tests conducted across the four equations, this is the likely result of sampling error. See Melick [1990] for graphs of each equation.

Table 1

Eigenvalues	0.056 0.080 0.422 0.452		
Unconditional Hypothesis Tests, Trace	Ho: $r > 3$ Ho: $r > 2$ Ho: $r > 1$ Ho: $r > 0$		3.412 8.306 40.643* 76.169*
Conditional Hypothesis Tests, Maximum Eigenvalue	Ho: $r = 3 \mid r = 4$ Ho: $r = 2 \mid r = 3$ Ho: $r = 1 \mid r = 2$ Ho: $r = 0 \mid r = 1$		3.412 4.894 32.337* 35.526*
Beta, assuming $r = 2$	*pm* *er* *cf* *pd* constant	–1.000 –0.615 –0.868 1.735 3.501	–1.000 –0.548 0.517 0.378 2.966
Hypothesis Tests of Restrictions Across Rows of β	$\beta'_{3,1} = -\beta'_{2,1}$ 20.748* $\beta'_{4,1} = \beta'_{2,1} - \beta'_{1,1}$ 17.704* $\beta'_{3,1} = -\beta'_{2,1}$ and $\beta'_{4,1} = \beta'_{2,1} - \beta'_{3,1}$ 43.304*		

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

between the variables. There is an additional equilibrium relationship between the four variables that is not captured by the Hooper-Mann model. Since the variables will respond to departures from both of the equilibrium relationships, the Hooper-Mann model, at a minimum, provides only a partial understanding of the system.

Moreover, it may be that neither of the two cointegrating vectors is consistent with the predictions of the Hooper-Mann model. Expressing the Hooper-Mann model, (13), in logarithms yields

$$pm = -(1-\sigma)\cdot er + (1-\sigma)\cdot cf + \sigma\cdot pd \qquad (17)$$

This can be written as

$$[pm \;\; er \;\; cf \;\; cd] \cdot \begin{bmatrix} -1 \\ -(1-\sigma) \\ 1-\sigma \\ \sigma \end{bmatrix} = 0 \tag{18}$$

or in terms of the Johansen and Juselius notation as

$$X \cdot \beta' = 0 \tag{19}$$

where β is the cointegrating vector. The mark-up model imposes two restrictions on the elements of the cointegrating vector in (18),

$$\beta'_{3,1} = -\beta'_{2,1} \tag{20}$$

$$\beta'_{4,1} = \beta'_{2,1} - \beta'_{1,1} \tag{21}$$

As shown at the bottom of Table 1, the restrictions in (20) and (21) are soundly rejected. In summary, the four variable system is not consistent with the mark-up model on two counts: 1) There are two, instead of one, cointegrating vectors, and 2) the restrictions implicit in the mark-up model are rejected.

In an attempt to see if the aggregate data is consistent with any of the theoretical models presented in section II, the remaining two models are estimated in turn with the Johansen procedure. Data generated in a competitive world would yield three co-integrating vectors corresponding to equations (2)–(4). In logarithmic form these cointegrating vectors (equations (2)–(4)) would be

$$pd - cd = ln(1 + r^d) \approx r^d \tag{22}$$

$$pm + er - cf = ln(1 + r^f) \approx r^f \tag{23}$$

$$pm - pd = 0 \tag{24}$$

However, the Johansen procedure cannot uniquely identify co-integrating vectors (Any linear combination of co-integrating vectors is itself a co-integrating vector). Therefore, to test the theory, only restrictions that can be placed on an arbitrary linear combination of the cointegrating vectors can be tested. An arbitrary linear combination of (22)–(24) would be given by (where each equation (cointegrating relationship or vector) becomes a column vector, and K, Θ and Ω are arbitrary constants)

$$K\cdot\begin{bmatrix}0\\0\\0\\1\\-1\\r^d\end{bmatrix}+\Theta\cdot\begin{bmatrix}-1\\-1\\1\\0\\0\\r^f\end{bmatrix}+\Omega\cdot\begin{bmatrix}-1\\0\\0\\1\\0\\0\end{bmatrix}=\begin{bmatrix}-\Theta-\Omega\\-\Theta\\\Theta\\K+\Omega\\-K\\-K\cdot r^d+\Theta\cdot r^f\end{bmatrix}=\beta' \qquad (25)$$

Two restrictions can be placed across the six rows of the right-hand side of (25),

$$\beta'_{3,1}=\beta'_{2,1} \qquad (26)$$

$$\beta'_{5,1}=-(\beta'_{1,1}-\beta'_{2,1}+\beta'_{4,1}) \qquad (27)$$

Table 2 presents the results of analyzing the 5 variable system of ***pm***, ***er***, ***cf***, ***pd***, and ***cd*** (the variables found in the competitive model). The procedure is identifying two co-integrating vectors among these variables, rather than the three cointegrating vectors suggested by the theory ((22)–(24)). Moreover, as shown at the bottom of Table 2, the restrictions implicit in the competitive model ((26) and (27)) are rejected. The predictions of the competitive model, like those from the Hooper-Mann model, are refuted.

Finally, the data might be generated in a non-competitive world described by (10) and (11). In this formulation the data are expressed in levels (instead of log levels), and CF and ER do not enter independently in any of the co-integrating vectors. For simplicity, (10) and (11) can be written as

$$PM=\varpi\cdot CD+\kappa\cdot\frac{CF}{ER} \qquad (28)$$

$$PD=\varphi\cdot\frac{CF}{ER}+\kappa\cdot CD \qquad (29)$$

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

$$K\cdot\begin{bmatrix}-1\\\kappa\\0\\\varpi\end{bmatrix}+\Theta\cdot\begin{bmatrix}0\\\varphi\\-1\\\kappa\end{bmatrix}=\begin{bmatrix}-K\\K\kappa+\Theta\cdot\varphi\\-\Theta\\K\cdot\varpi+\Theta\cdot\kappa\end{bmatrix} \qquad (30)$$

Table 2

Eigenvalues	0.047 0.065 0.265 0.468 0.492		
Unconditional Hypothesis Tests, Trace	Ho: $r > 4$ Ho: $r > 3$ Ho: $r > 2$ Ho: $r > 1$ Ho: $r > 0$		2.839 6.808 25.004 62.201* 102.208*
Conditional Hypothesis Tests, Maximum Eigenvalue	Ho: $r = 4 \mid r = 5$ Ho: $r = 3 \mid r = 4$ Ho: $r = 2 \mid r = 3$ Ho: $r = 1 \mid r = 2$ Ho: $r = 0 \mid r = 1$		2.839 3.969 18.196 37.198* 40.007*
Beta, assuming $r = 2$	*pm* *er* *cf* *pd* *cd*	–1.000 –0.591 –0.301 1.433 –0.280	–1.000 –0.446 1.018 –0.004 –0.146
Hypothesis Tests of Restrictions Across Rows of β	$-\beta'_{3,1} = \beta'_{2,1}$ 18.607* $\beta'_{5,1} = -(\beta'_{1,1} - \beta'_{2,1} + \beta'_{4,1})$ 20.014* $-\beta'_{3,1} = \beta'_{2,1}$ and $\beta'_{5,1} = -(\beta'_{1,1} - \beta'_{2,1} + \beta'_{4,1})$ 42.439*		

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

Unlike the competitive case, no restrictions can be imposed on the rows of the right-hand side of (30). Table 3 presents results for this system. Two cointegrating vectors are identified, consistent with the model. Given that the theory does not impose any restrictions on the four variable system, the five variable system of *PM*, *CF/ER*, *CF*, *PD*, and *CD* was estimated to generate the restriction that the coefficient on *CF* be equal to zero in all cointegrating vectors. This restriction, reported at the bottom of Table 3, is rejected. As for the other models, support is lacking for the Nash competi-

Table 3

Eigenvalues	0.0006 0.0737 0.2656 0.3970 0.4644		
Unconditional Hypothesis Tests, Trace	Ho: $r > 4$		0.036
	Ho: $r > 3$		4.556
	Ho: $r > 2$		22.772
	Ho: $r > 1$		52.611*
	Ho: $r > 0$		89.444*
Conditional Hypothesis Tests, Maximum Eigenvalue	Ho: $r = 4 \mid r = 5$		0.036
	Ho: $r = 3 \mid r = 4$		4.520
	Ho: $r = 2 \mid r = 3$		18.215
	Ho: $r = 1 \mid r = 2$		29.840*
	Ho: $r = 0 \mid r = 1$		36.833*
Beta, assuming $r = 2$	*PM*	−1.000	−1.000
	CF/ER	68.805	50.707
	PD	2.073	0.498
	CD	−0.354	−0.226
	CF	−1.534	0.034
Hypothesis Tests of Restrictions Across Rows of β	$\beta'_{5,1} = 0$ 17.116		

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

tors model.

None of the section II models seems to stand-up to the scrutiny of the data, not a surprising result given 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, should not be expected to be consistent with a single theoretical model. 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.* Feenstra, Marston, Knetter [1993], Mohamed [1990]).

V. Conclusion

This paper makes two points. First, an econometric equation demonstrating instability is quite likely the result of misspecification, and should not be taken as evidence in favor of a theoretical model. Second, pass-through at the macroeconomic level is a complicated amalgamation of disparate industrial structures. Examination of aggregate data with only one model in mind is not a fruitful exercise.

Data Appendix

The following brief data descriptions are for the most part taken directly from Hooper–Mann:

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.

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.

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