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STOCK-FLOW RELATIONSHIPS IN US HOUSING CONSTRUCTION

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I. INTRODUCTION

The statistical formulation of an econometric model is viewed as a sequence of marginalizing and conditioning operations which reduce the parameterization to manageable dimensions. Hendry and Richard (1982) discussed such a modeling strategy which reduces a general model to a parsimonious, data-based, and theory-consistent summary. In this framework, Hendry (1984) and Ericsson and Hendry (1985) discuss an econometric model for UK new house prices and report various empirical results, based on work in Ericsson (1978).

Hendry (1986) presents an empirical econometric model for the levels of starts and completions and the stock of work in progress for new private dwellings in the UK. He illustrates both the theoretical issues and a substantive econometric model to aid understanding of how housing construction markets operate. In his housing construction model the stock-flow relationships play an important role in modeling. The housing starts and housing completions series are the flow variables, and housing units under construction is the stock variable. It is interesting to note that the stock variable is obtained by accumulating the difference of the two flow variables. The stock of housing units under construction is the accumulated sum of uncompleted starts.

In this paper, the housing construction model in Hendry (1986) is investigated by testing cointegration between starts, completions, and the stock of housing units under construction in the US. This paper does not include all the features of the housing market considered in Ericsson and Hendry (1985) and Hendry (1986). However, it represents the form that a model should have in order to satisfy the long-run equilibrium relationships between starts, completions and the housing units under construction. Other potential explanatory variables such as the rate of property taxes, interest rates, GNP, a price index of house, or the stock of unsold completions can be added to the

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model. These extensions can be referred to the papers cited earlier. We focus here only on the stock-flow relationship.

A similar relationship for the inventory model is studied by Granger and Lee (1989, 1990) and Lee (1990) using the concept of multicointegration. The production and sales series are the flow variables, and the level of inventory is the stock variable. The level of inventory is the accumulated sum of production minus sales.

We discuss the concept of multicointegration and the error correction models in Section II. Then we present the empirical results in Section III and conclude in Section IV.

II. MULTICOINTEGRATION

A random variable is called integrated of order d, denoted $I(d)$, if the dth difference of the random variable can be represented by a stationary and invertible autoregressive and moving average (ARMA) process. It is widely believed that $d=1$ in many economic time series, and there is a long swing dominant component in the series characterized by a unit root.

While the unit root can be removed by first differencing, if several of these integrated series can be linearly combined so that the dominant common component is cancelled, then the set of integrated series is called *cointegrated.* The presence of cointegration implies the co-movement of the set of series, having an equilibrium property in the long run, sharing some common factors (common stochastic trends), and showing short run dynamics through error correction.

A research in this area is motivated from the stock-flow links of economic variables. Granger (1986) and Granger and Lee (1990) introduce a deeper form of cointegration, called multicointegration. Granger and Lee (1989) and Lee (1990) examine empirically the presence of multicointegration in the production, sales, and the level of inventory series in many US industries. Another example of multicointegration is investigated in this paper for the US housing construction data.

Multicointegration can be defined as follows. If s_t, c_t are both $I(1)$ and if $z_t \equiv s_t - c_t$ is $I(0)$ then s_t and c_t are cointegrated. Since z_t is $I(0)$, $u_t \equiv \Sigma_{j=0}^{t} z_{t-j}$ will be $I(1)$. If s_t and u_t are cointegrated, s_t and c_t will be said to be *multicointegrated.* c_t and u_t will also be cointegrated. Then it follows that $w_t \equiv c_t - \kappa u_t$ is $I(0)$ for a constant κ. Generally, s_t and c_t are flow variables, and u_t is a stock variable. Note that u_t is the accumulated sum of z_t.

For the inventory example, s_t is production, c_t is sales, z_t is the change in inventories, and u_t is the level of inventory. For the housing construction example, s_t is new housing units started, c_t is new housing units completed, z_t is the uncompleted starts, and u_t is the housing units under construction.

It is proved in Granger and Lee (1990) (the representation theorem for multicointegration) that if s_t, c_t and u_t are $I(1)$, and if $z_t \equiv s_t - c_t$ and

$w_t = c_t - \kappa u_t$ are $I(0)$, then the following models can be considered as the data generating processes of s_t, c_t and u_t:

$$\Delta s_t = \alpha_1 + \beta_1 z_{t-1} + \gamma_1 w_{t-1} + \text{lagged}(\Delta s_t, \Delta c_t) + \varepsilon_{1t}$$

$$\Delta c_t = \alpha_2 + \beta_2 z_{t-1} + \gamma_2 w_{t-1} + \text{lagged}(\Delta s_t, \Delta c_t) + \varepsilon_{2t}$$

$$\Delta u_t = \alpha_3 + \beta_3 z_{t-1} + \gamma_3 w_{t-1} + \text{lagged}(\Delta s_t, \Delta c_t) + \varepsilon_{3t}$$

where $\Delta x_t = x_t - x_{t-1}$. These models guarantee the long-run equilibrium relationships between s_t and c_t, and between c_t and u_t. These are the error correction models for the multicointegrated series in which the changes in s_t, c_t and u_t are related to the lagged errors, z_{t-1} and w_{t-1}. We call z_{t-1} a proportional error correction mechanism, w_{t-1} an integral error correction mechanism, and the lagged Δs_t and Δc_t derivative error correction mechanisms. Thus the error correction models for multicointegrated series are a proportional-integral-derivative (PID) feedback controller, familiar to control engineers (Kwakernaak and Sivan, 1972). Phillips (1954) enumerate these three types of feedback control mechanisms in the context of economic stabilization policy.

Assuming that market forces make builders who fail to minimize costs leave the market, we would formulate an optimization problem. Three costs can be considered: the cost of uncompleted starts (z_t), the cost of holding an inadequate housing stock under construction (w_t), and the cost of adjusting the rate of completions (Δc_t). A representative builder minimizes the expected discounted present value of an additively separable and quadratic cost function

$$E_t \sum_{j=0}^{\infty} \delta^j [z_{t+j}^2 + \theta_1 w_{t+j}^2 + \theta_2 (\Delta c_{t+j})^2],$$

subject to (1). If s_t, c_t and u_t are $I(1)$, the three elements in the cost function z_t, w_t and Δc_t are all $I(0)$. E_t denotes the conditional expectation given an information set at time t, δ is a discount rate that is less than one, and θ_1, θ_2 are nonnegative. Hendry (1986) and Lee (1990) show that the error correction models can be derived from this intertemporal optimization problem, so that the error correction models can be considered as optimal control rules.

III. EMPIRICAL STUDY

The procedures used here to test for unit roots and cointegration are based on works by Phillips (1987), Phillips and Perron (1988), Perron (1988), Johansen (1988), and Johansen and Juselius (1990). To minimize space for presentation the same notation is used as in the original works.

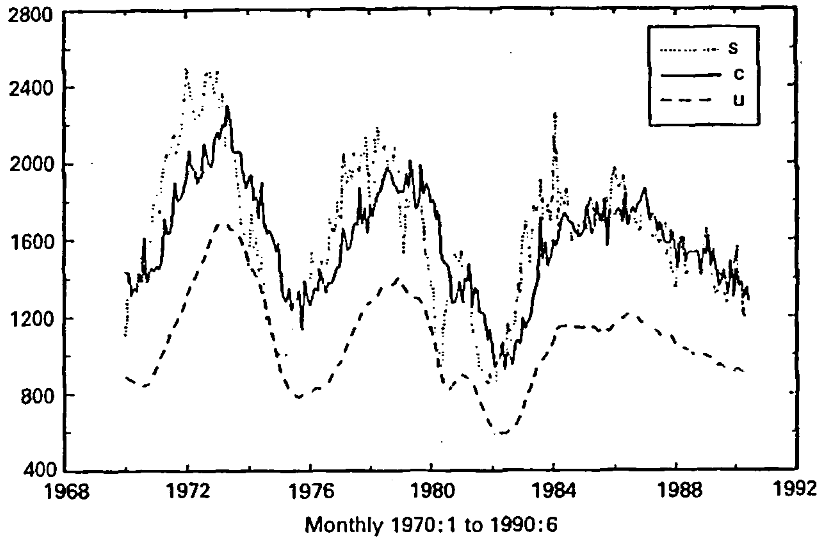

Fig. 1. s_t, c and u_t

3.1. The Data

The data are from the Citibase: new privately owned housing units started (the Citibase name is HSFR); new privately owned housing units completed (HCP); and new privately owned housing units under construction (HUCP). The sample is monthly from January 1970 to June 1990 with 246 observations and seasonally adjusted.[1]

The plots of these series are given in Figure 1. Several comments on the plots can be summarized as follows: (a) there may be a unit root in each series, (b) they move together, (c) there is no trend in any series, (d) starts are more volatile than completions, (e) the stock variable is much smoother than the flow variables, (f) starts lead completions, and (g) there seems to be no lead or lag between completions and the housing stock under construction.

Let s_t be the starts, c_t the completions of new houses at time t, and u_t the stock of uncompleted houses at the end of time t. Then u_t is the integral of past uncompleted starts, that is

$$u_t \equiv u_{t-1} + s_t - c_t. \tag{1}$$

To be consistent with the idea of multicointegration we generate u_t from the identity (1) using the other two series, as in the work of Ericsson and Hendry (1985) and Hendry (1986), and also as in the inventory study of Granger and Lee (1989, 1990) and Lee (1990), rather than use all of the three series from the Citibase.

[1] Only seasonally adjusted data are available in the Citibase.

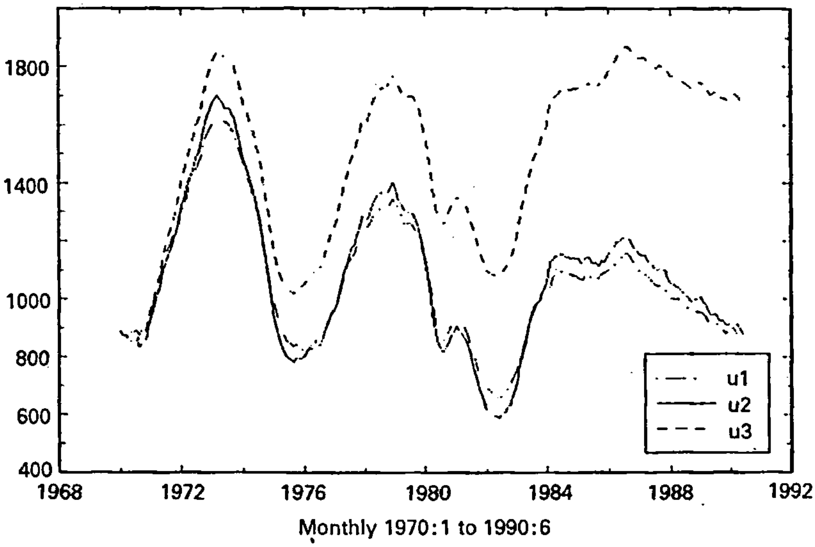

Fig. 2. The alternative series for u_t

(u1) the Citibase series (HUCP), (u2) $u_t = u_0 + \Sigma_{j=1}^{t}(0.98s_j - c_j)$ and (u3) $u_t = u_0 + \Sigma_{j=1}^{t}(s_j - c_j)$.

However, the series u_t obtained from the identity is quite different from the Citibase series (Figure 2). It could possibly be because some building companies go bankrupt and some starts are therefore not completed, and it could also be due to recording errors. The possibility that dwellings disappear by demolition, fire or conversion to other uses would also affect the identity. We remedy this problem as follows.

Liu (1990) proves that if s_t and c_t are multicointegrated there should be leads or lags between the series.[2] Thus we estimate a finite distributed lag model between s_t and c_t of the form $c_t = \Sigma_{i=n}^{m} \lambda_i s_{t-i} + e_t$ where e_t is a noise process and each $\lambda_i \geq 0$ is a proportion of starts at time $t-i$ which is completed at time t.[3] With our data the estimated sum of λ_i for $i = n, \ldots, m$, with various reasonable selection of n and m is around 0.98. This means that some starts were never completed.

In Figure 2 we plot three alternative series for u_t; ($u1$) the Citibase series (HUCP), ($u2$) $u_t = u_0 + \Sigma_{j=1}^{t}$ $(0.98s_j - c_j)$, and ($u3$) $u_t = u_0 + \Sigma_{j=1}^{t}$ $(s_j - c_j)$, where u_0 is a constant which makes the first observations u_1 of all three

[2] The lead-lag relationship can be investigated using the concept of *synchronization* developed by Granger (1988) and Liu (1990), and can be tested in that context. Two series are called completely synchronized if the phase spectrum of two variables is equal to zero for all frequencies. Thus synchronization is related to the co-movement of time series without leads or lags. Liu (1990) proves that multicointegrated series are not completely synchronized.

[3] See Hendry (1986).

alternatives equal. The series $u2$ is very similar to the series $u1$, while the series $u3$ diverges from the Citibase series more and more over time because of the cumulation of the never-completed starts. Hence from now on we use $z_t \equiv (0.98s_t - c_t)$ and $u_t \equiv u_0 + \Sigma_{j=1}^{t} z_j$.

3.2. *The Phillips–Perron Test*

In Table 1 the results of the Phillips–Perron test for $0.98s_t$, c_t, u_t, z_t and w_t are presented. The summary of the test statistics can be found in Perron (1988, pp. 308–9). In calculating the test statistics the Newey–West (1987) lag truncation parameter $l = 0, 1, \ldots, 12$ were used, but only the results for $l = 7$ are reported. The results were similar for other values of l. As the Phillips–Perron test statistics are asymptotically equivalent to the corresponding Dickey–Fuller test, the critical values are taken from Dickey and Fuller (1981) and Fuller (1976).

There is strong evidence for the presence of a unit root in c_t and u_t, and marginally in $0.98s_t$. The tests firmly reject the null hypothesis of a unit root in z_t. Thus the flow series, $0.98s_t$ and c_t, are cointegrated. The plot of z_t in Figure 3 shows that z_t is stationary and has a short memory, fluctuating frequently around its unconditional mean. This means that the proportional error z_t is significantly corrected.

w_t is obtained as the OLS residuals from the regression of c_t on a *constant* and u_t. The adjusted coefficient of determination ($\bar{R}^2$) of the OLS regression is 0.89. The Durbin–Watson statistic for w_t is 1.09 which implies the first order autocorrelation coefficient of w_t is approximately 0.46. Figure 4 shows that w_t also has a very short memory, meaning that the correction of the integral error w_t is significant. Since w_t has a zero mean, the Phillips–Perron

TABLE 1
The Phillips–Perron Test

	$0.98\ s_t$	c_t	u_t	z_t	w_t
$Z(\hat{\alpha})$	−0.54	−0.33	−0.37	−46.18**	−177.01**
$Z(t_{\hat{\alpha}})$	−0.50	−0.46	−0.43	−5.10**	−10.52**
$Z(\alpha^*)$	−15.03*	−10.48	−6.84	−46.17**	−177.00**
$Z(t_{\alpha^*})$	−2.81	−2.27	−1.84	−5.09**	−10.50**
$Z(\phi_1)$	3.95	2.57	1.70	12.96**	55.15**
$Z(\tilde{\alpha})$	−17.26	−11.96	−7.95	−47.01**	−177.05**
$Z(t_{\tilde{\alpha}})$	−3.14	−2.51	−2.09	−5.15**	−10.49**
$Z(\phi_3)$	5.27	3.34	2.44	13.34**	55.01**
$Z(\phi_2)$	3.52	2.23	1.63	8.90**	36.68**

Note:
* and ** denote the significance at 5 percent and 1 percent levels, respectively.

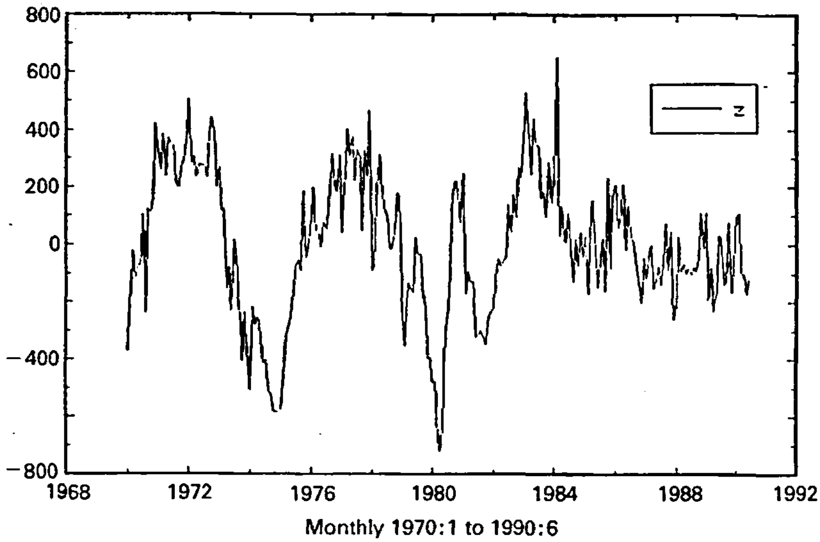

Fig. 3. z_t

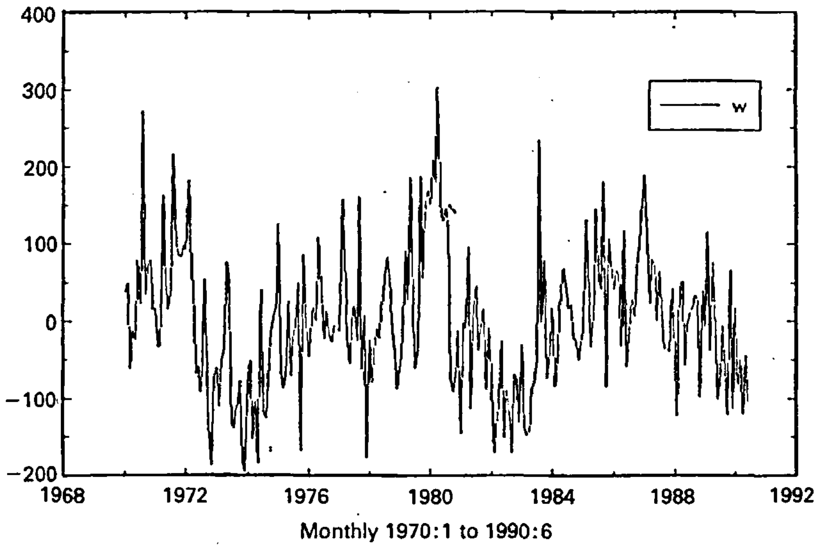

Fig. 4. w_t

test is based on the regression without a constant or a trend. It should be noted that the same critical values can not be used for w_t since w_t is estimated. The critical values for $t_{\hat{a}}$ are available in Engle and Yoo (1987), however, the statistics are high enough to say that there is no unit root in w_t. The stock series u_t is therefore cointegrated with the flow series c_t.

3.3. *The Johansen Test*

On the basis of the plots of the series in Figure 1 and the results of the Phillips–Perron tests, we consider a model without a linear trend. If a $p \times 1$ vector X_t is generated by the error correction model

$$\Delta X_t = \Gamma_1 \Delta X_{t-1} + \ldots + \Gamma_{k-1} \Delta X_{t-k+1} + \Pi X_{t-k} + \mu + \varepsilon_t \tag{2}$$

where ε_t is an i.i.d. Gaussian random vector, the Johansen test for the null hypothesis that the rank of Π is at most r is based on the $p-r$ smallest squared canonical correlations of $(X'_{t-k} 1)$ with respect to ΔX_t corrected for the lagged differences of X_t. Note that a constant term is appended to the vector X_{t-k}. The number k should be chosen by the user so that ε_t be i.i.d. Two statistics called the trace statistic (trace) and the maximal eigenvalue statistic ($\lambda_{\max}$) are reported in Table 2. The statistics allow us to determine the rank of cointegration (r) and the number of the common factors ($m = p - r$). The critical values are taken from Johansen and Juselius (1990, p. 209).

We apply the Johansen test to $X_t = z_t$ which is the case when $p = 1$. In this case the Johansen test is used for testing a unit root in z_t. For $k = 1$, 2 and 3, the statistics were 23.76, 11.30, and 9.82, respectively, rejecting the null hypothesis of a unit root at least 5 percent level.

In Table 2, the results of the Johansen test for $X_t = (c_t u_t)'$ are reported with $k = 1$, 2 and 3. Since the Johansen test seems sensitive to the choice of k, the p-values of the various residual ($\hat{\varepsilon}_t$) diagnostics are presented in Table 3; (a) the Wooldridge's (1990) robust regression based Lagrange Multiplier (LM) tests for autocorrelations (AR) and autoregressive conditional heteroskedasticity (ARCH) of orders up to 1, 2, 4, 7, 10, (2) the Ljung–Box portmanteau test for up to 20th order serial correlations in the residuals, (c) the McLeod and Li (1983) test for up to 20th order serial correlations in the squared residuals, (d) the Jarque and Bera (1980) test for normality, and the tests for skewness and kurtosis, (e) the White's (1989) neural network test for neglected nonlinearity, and (f) the test for nonsymmetric error correction model.

The AIC and SIC criteria are also computed for the system of error correction models for $X_t = (c_t u_t)'$. For $k = 1$, 2 and 3, the AIC's are 3838.5, 3812.1,

TABLE 2
The Johansen Test for $X_t = (c_t u_t)'$

H_0	*Statistic*	$k=1$	$k=2$	$k=3$
$r=0$	trace	81.24**	40.41**	37.04**
	$\lambda_{\max}$	80.65**	33.05**	25.22**
$r=1$	trace, $\lambda_{\max}$	0.59	7.36	11.83*

Note: See Table 1.

and 3799.8, respectively, and the SIC's are 3866.4, 3854.0, and 3855.6, respectively. Among $k=1$, 2 and 3, $k=3$ is selected by the AIC while $k=2$ by the SIC.

We reject the null hypothesis that the cointegrating rank (r) is zero and accept the null that $r=1$ for $X_t=(c_t u_t)'$. Thus the flow (c_t) and the stock (u_t) are cointegrated.

It may be noted that the Johansen test can not be used for $X_t=(0.98s_t c_t u_t)'$ or $X_t=(0.98s_t c_t)'$ without further modification. This is because if s_t and c_t are multicointegrated and the identity (1) holds, the error correction models (2) should include integral error correction terms. Otherwise ε_t will be a non-invertible moving average process. See Granger and Lee (1990, p. 82, equation B.4). This would be a similar case where differencing the model

TABLE 3
P-Values of the Specification Tests

	Δc_t			Δu_t		
Test	*k=1*	*k=2*	*k=3*	*k=1*	*k=2*	*k=3*
LM Test						
AR(1)	0.03	0.02	0.83	0.00	0.72	0.15
AR(2)	0.73	0.03	0.33	0.97	0.91	0.37
AR(4)	1.00	1.00	0.64	0.70	0.95	1.00
AR(7)	1.00	0.97	1.00	0.97	0.98	1.00
AR(10)	1.00	1.00	1.00	1.00	1.00	1.00
LM Test						
ARCH(1)	0.03	0.08	0.10	0.35	0.29	0.29
ARCH(2)	0.47	0.05	0.75	0.79	0.42	0.97
ARCH(4)	1.00	0.75	0.95	0.76	1.00	0.99
ARCH(7)	1.00	1.00	0.94	1.00	0.97	0.73
ARCH(10)	1.00	1.00	1.00	0.98	1.00	1.00
Ljung-Box (20)	0.73	0.90	0.96	0.44	0.90	0.90
McLeod-Li (20)	0.78	0.79	0.81	0.47	0.13	0.17
Jarque-Bera (2)	0.01	0.00	0.00	0.17	0.37	0.42
skewness (1)	0.01	0.00	0.00	0.22	0.45	0.46
kurtosis (1)	0.12	0.07	0.06	0.16	0.23	0.27
Neural Network (3)	0.78	0.07	0.23	0.67	0.38	0.72
Nonsymmetric ECM (1)	0.29	0.26	0.31	0.37	0.41	0.42

Notes: Each test statistic follows the chi-square distribution with degree of freedom equal to the number in ( ). For the neural network test for neglected nonlinearity we use 10 phantom hidden units, 3 principal components of them and 5 draws on the test to compute the Hochberg's Bonferroni bound (see Lee, White and Granger, 1992).

TABLE 4
The Error Correction Models

Dependent variable	Constant	Independent variables w_{t-1}	z_{t-1}	z_{t-2}	Δc_{t-1}	Δc_{t-2}
Δc_t	−0.40	−0.30	0.83	0.61	−0.37	−0.09
	(−0.09)	(−4.94)	(2.29)	(1.69)	(−5.28)	(−1.57)
z_t	−0.03	0.04	0.65	0.23	0.02	0.01
	(−0.03)	(2.82)	(8.72)	(3.41)	(1.23)	(0.54)

Note: White's heteroskedasticity consistent t values are in ( ). $k=2$. $z_t=\Delta u_t$.

leads to overdifferencing the error vector. Engle and Yoo (1989) thus suggest to relate multicointegration to the case of $I(2)$ cointegration. See Gregoir and Laroque (1990) for further discussion.

3.4. The Error Correction Models

The estimated error correction models for $X_t=(c_t u_t)'$ using $k=2$ are reported n Table 4 with the White's (1980) heteroskedasticity consistent t-values in brackets. Note that $\Delta u_t=z_t$, and thus the second error correction model is a stock adjustment model. If z_t and w_t were $I(1)$ so that the estimates of the corresponding coefficients are asymptotically zero, then the t-statistics in the brackets would not follow the standard t-distribution. Assumed that z_t and w_t are $I(0)$ based on the previous results of the unit root tests, it appears that the proportional error corrections and the integral error corrections occur significantly in both Δc_t and z_t equations.

As the coefficient of the z_{t-1} in the Δc_t equation is significant and positive, we may predict an increase in housing completions at time t if there were uncompleted starts at time $t-1$. Also as the coefficient of the w_{t-1} in the Δc_t equation is significant and negative, it may be expected that builders will reduce the rate of the housing completions at time t if the completions was too much relative to the stock of houses under construction at time $t-1$. It is these short-run adjustment processes through the proportional and integral error corrections that lead to the flow-flow relationship and the stock-flow relationship in the long run in the housing construction market.

In Table 3 the nonsymmetric error correction models introduced in Granger and Lee (1989) are tested to see if the strength of attraction (speed of adjustment) is different on both sides of the attractor.[4] That is, we test if the coefficients of w^+_{t-1} and w^-_{t-1} are equal, where $w^+=\max(w,0)$ and $w^-=\min(w,0)$. We do not reject the symmetric error correction. The cost of

[4] See Granger (1987).

too fast completions relative to the housing stock under construction (w^{+}_{t-1}) may not be significantly different from the cost of the opposite case, w^{-}_{t-1}.

IV. CONCLUSIONS

The housing and construction series have been considered as important indicators of economic activity and aggregate fluctuations. The new building permits series is currently used as one of the 11 series for the US Department of Commerce's composite index of leading indicators.

In this paper we find clear evidence for the presence of the stock-flow links in the US housing construction data. It is suggested from the estimated error correction models that the consideration of the integral correction for the stock-flow relationship would improve the predictability of the series involved. Thus the concept of multicointegration may provide a useful characterization of these time series for overall economic conditions.

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