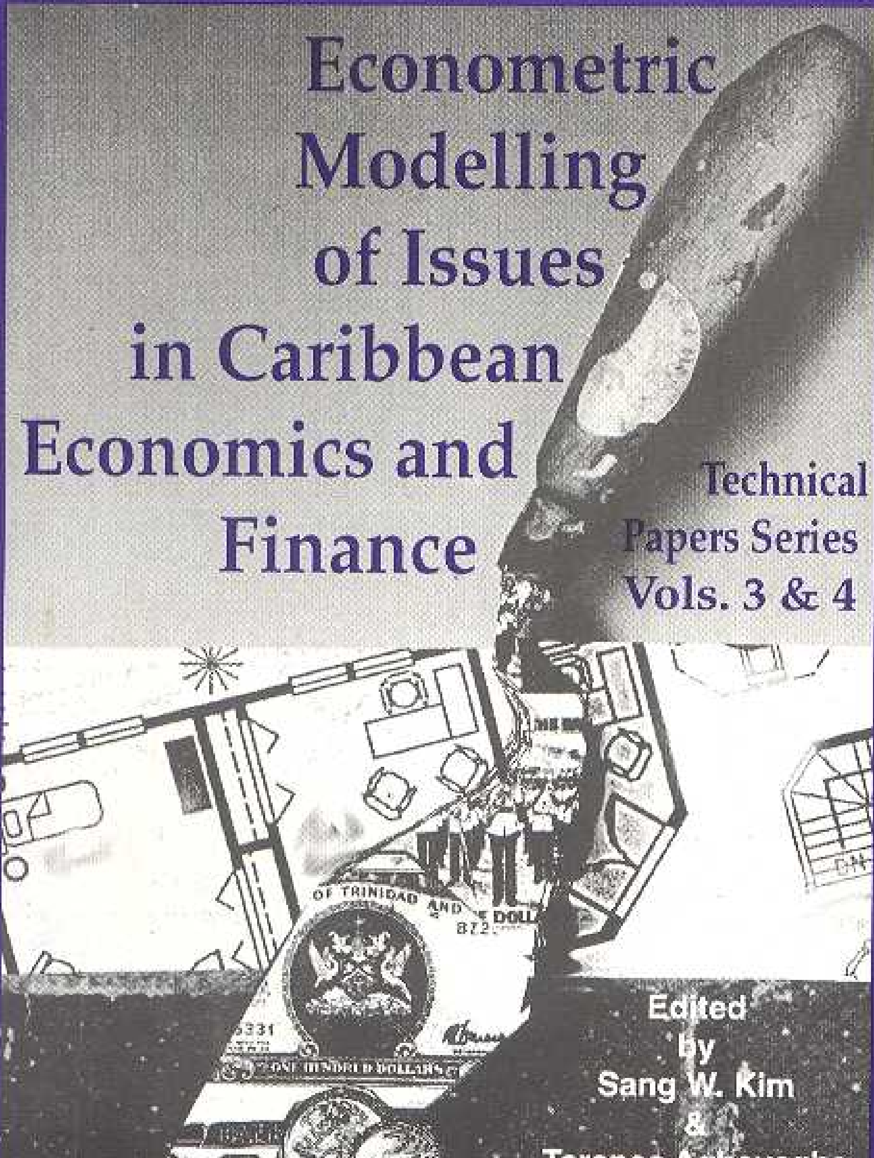
# Econometric Modelling of Issues in Caribbean Economics and Finance

Technical Papers Series
Vols. 3 & 4




Edited
by
Sang W. Kim
&
Terence Agbeyegbe

Caribbean Centre
for Monetary Studies

# ECONOMETRIC MODELLING OF ISSUES IN CARIBBEAN ECONOMICS AND FINANCE

*This is the third publication in the Technical Papers Series (TPS) of the Caribbean Centre for Monetary Studies. This edition of the TPS, Volumes 3 and 4, contains select papers at the cutting edge of attempts to deal with the problems inherent in executing applied econometric research in a Caribbean environment characterised by short data sets and the paucity of high frequency data. Volumes 3 and 4 therefore examine issues such as the usefulness of the state space modelling approach, investigating various stock market phenomena in a GARCH framework, testing for exogeneity and super-exogeneity using the error correction methodology, the use of VARs to model inflation and testing for the validity of purchasing power parity.*

## ABOUT THE EDITORS

***Sang W. Kim** is a lecturer in the Department of Economics at The University of the West Indies at Mona. He teaches Econometrics, International Finance and Financial Economics. He received his Ph.D in Economics from The Pennsylvania State University. His research interests include: emerging financial markets, exchange rate determination and volatility spillovers in stock markets.*

***Terence D. Agbeyegbe** graduated with a B.A. (Hons.) in Mathematical Economics from the University of Essex, United Kingdom, an M.Sc in Statistics from University College, London and an M.Sc. in Economics from the London School of Economics and Political Science. He also has a Ph.D. in Economics from the University of Essex, United Kingdom. From 1983-1989, he was an assistant professor of economics at Rutgers-The State University of New Jersey, New Brunswick. From 1989-1995, he was an associate professor of economics at Hunter College and The Graduate Center of The City University of New York. Since 1996 he has held a full professorship position at the named institution. He is also a research associate and a member of the editorial board of the Technical Papers Series of The Caribbean Center for Monetary Studies, The University of the West Indies, St. Augustine, Trinidad and Tobago. Professor Agbeyegbe has served as an associate editor with Evaluation Review. He is currently serving as associate editor with The Journal of African Finance and Economic Development and also with The Journal of Asian Economics. Professor Agbeyegbe has numerous publications in academic journals and books. Since coming to The City University, he has done extensive work in India, Jamaica and Nigeria. In 1994 for example, he was commissioned by the United Nations Development Programme to work at the National Planning Commission in Lagos, Nigeria.*

**Caribbean Centre for Monetary Studies**

Established under the joint auspicies of the Central Banks of the Caribbean Community and The University of the West Indies

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## PREFACE

This edition of the Technical Papers Series contains papers which were either presented or submitted for review at the Modelling Session of the 1996 and 1997 Annual Conferences of the Caribbean Centre for Monetary Studies. As always, the papers presented in this Session utilise new modelling or econometric techniques or an application of those techniques to a new set of data and/or economic issues. Papers in this edition are no exception.

Ed Chartey's paper applies the error correction methodology to the examination of exogeneity and super-exogeneity in the context of the empirical study of money demand in Guyana, Jamaica and Trinidad and Tobago.

Then there are papers that utilise various econometric methodologies to model economic relationships. Jacqueline Hamilton uses the Generalized Autogressive Conditional Heteroscedasticity (GARCH) methodology to model the conditional variance of selected stock returns on the Jamaica Stock Exchange. She finds that unlike the developed stock markets, very little of the persistent risk of returns on the Jamaica Stock Exchange is explained by GARCH effects.

Sang W. Kim and Brian Langrin apply a similar GARCH modelling strategy to examine the effects of stock market volatility spillovers between Jamaica, Trinidad and Tobago, Barbados and the United States. In light of the liberalization of the foreign exchange markets in Trinidad and Tobago and Jamaica in the early 1990s, they develop a three-step modelling strategy where the volatility spillovers among the markets are carefully measured. They find that while there are some volatility spillovers from the United States to the markets in the Caribbean, these spillovers increased significantly after the foreign exchange market liberalization in

Jamaica, while the spillovers remained relatively insignificant in Trinidad and Tobago. They conclude, therefore, that prior to liberalization, foreign exchange restrictions were more binding in Jamaica than in Trinidad and Tobago.

Wayne Robinson applies the Vector Autoregression (VAR) methodology to model inflation in Jamaica. In comparison to other methods utilized in previous studies, he finds the VAR methodology to be more appropriate with better forecasting properties.

Alain Maurin, seeks to overcome the problems of short data sets and the paucity of higher frequency data by using state space modelling. Applying the technique to tourism data, money and output data in Barbados and various macroeconomic data in Trinidad and Tobago, he finds that the model has a good in-sample forecasting performance and, perhaps more importantly, forecasts which are more reliable.

Finally, Anston Rambarran in "Purchasing Power Parity (PPP) in the CARICOM region, 1973-1995: Evidence and Policy Implications" provides evidence of the validity of PPP in the CARICOM region. Rambarran argues for the use of effective as opposed to bilateral exchange rates in tests of PPP. Such a consideration is particularly important since less developed countries are generally unable to avoid fluctuations in their effective exchange rates, despite pegging to a major currency or to a basket of currencies that float against each other. He tests the validity of PPP in a number of ways and obtains results that are mixed. The multivariate Johansen tests for cointegration are generally supportive whereas the Engle-Granger tests are not supportive of the long-run PPP relationship. Rambarran concludes that PPP is not sufficient as an explanation of exchange rate determination. Interestingly, notwithstanding the mixed nature of the results, this paper points out some macroeconomic policy implications of the validity of long-run PPP for the Caribbean region. For countries operating under fixed exchange rate regimes, namely: Barbados and the Organization of Eastern Caribbean States, the efficacy of domestic monetary and fiscal policies are weakened in terms of maintaining price stability, except to the extent that these policies can influence the international price level in some significant manner. For countries operating under flexible exchange rate regimes, namely: Guyana, Trinidad and Tobago and Jamaica, there is some degree of autonomy in using monetary and fiscal policies to achieve price stability.

These papers provide a glimpse into the type of empirical economic research being carried out in the Caribbean. The authors and editors hope that this volume adds value to our knowledge of econometric modelling in the Caribbean.

# CHAPTER 1

# TESTING FOR WEAK- AND SUPER-EXOGENEITY CONDITIONS OF MONEY DEMAND FUNCTIONS IN SOME CARIBBEAN NATIONS

*Edward E. Ghartey*

# Testing for Weak- and Super-Exogeneity Conditions of Money Demand Functions in Some Caribbean Nations

*Edward E. Ghartey*

## Introduction

In econometric estimation of the conventional money demand function it is often not clear whether or not the money stock, price and real income are to be treated as exogenous. This difficulty renders the appropriate use of econometric techniques for estimating the money demand function questionable, which then makes the resulting estimates unreliable for policy analysis and recommendations.

The typical conventional money demand function assumes that explanatory variables such as interest rates, real income, and other related variables are exogenous.[1] Thus the resulting formulated conventional money demand function is estimated by single equation estimating techniques. See Goldfeld (1973), and most of the previous studies in the Caribbean region such as Craigwell (1991). However, studies such as Sims (1972) questions the legitimacy of treating the money stock in the conventional money demand function as endogenous. According to Sims (1972), the real income rather than the money stock is endogenous, while the money stock is exogenous in such models. This means that it is inappropriate to use single equation estimating techniques to estimate the money demand function. See also Friedman and Schwartz (1963).

Other studies have also questioned the treatment of money stock as an endogenous variable in a conventional money demand function, but unlike Sims' (1972) study, price is considered to be endogenous, and money stock as exogenous because it is a controllable policy variable. See Cagan (1956), Carr, Darby and Thornton (1985), and Judd and Scadding (1982). However, it must be pointed out that the fact that the money stock is controllable does not mean that it is statistically exogenous. Infact, the money stock exhibits the characteristics of endogeneity more than exogeneity because central banks do not have a complete control over it, since the money multiplier which multiplies the monetary base or high-powered money to yield the money supply is endogenously determined by different agents, namely: the banks, non-banking public, and central banks. Additionally, although controllability is associated with exogeneity, Engle, Hendry, and Richard (1983) have demonstrated that if monetary aggregates are controllable, it does not mean that they are automatically exogenous.

The controversies surrounding the inadequate knowledge of which variables in conventional money demand function ought to be treated as exogenous or endogenous, have led some economists to suggest that the conventional money demand function must be specified as a complete structural model which incorporates both money demand and supply. In the structural form of such a model, relevent variables such as real income, price, money stock, and interest rates could all be treated as endogenous variables. See Brunner and Meltzer (1969).[2]

Interestingly, as rightly observed by Goldfeld (1973), the long-run estimates from both single and simultaneous equation techniques often yield results which are very similar. Thus the additional cost incurred for rightly modelling and estimating simultaneous equation models does not warrant the extra effort needed to correct the possibility of simultaneous bias which may results from the improper use of single equation estimating techniques.

Notwithstanding the above modelling controversies, variables in the conventional money demand function cannot be arbitrarily treated as exogenous and/or endogenous, because the exogeneity and endogeneity concepts are conditional. It is important to test to validate whether the price and/or real income in conditional money demand functions are weak- and super-exogenous. Using appropriate techniques to establish the exogeneity conditions of the model before estimation, will lend further confidence in the final use of the resulting estimates for policy analysis. Additionally, when the explanatory variables in the model satisfy the super-exogeneity property, the model automatically becomes structurally invariant, and therefore can be used for policy exercises and forecasting without being subjected to the policy deficiencies cited in the Lucas critique.

In the following paper, the exogeneity property of the money demand function is empirically tested in detail for the first time in the Caribbean for Barbados and Jamaica. Note that empirical tests of the exogeneity property of the money demand function are generally very limited as observed by Fisher (1993), and absent in most of the previous studies in the Caribbean region.

Following the introduction, weak-cxogeneity, stability of parameters of interest, and super-exogeneity of prices, and real income are discussed in section II. In section III, the empirical results designed within an error correction framework are discussed. The paper is concluded with a summary of the basic findings in section IV.

## II. WEAK- AND SUPER-EXOGENEITY

The concepts of weak-exogeneity, constancy, structural invariance, and super exogeneity are defined, discussed and demonstrated in Engle, Hendry, and Richard (1983). For this study we shall employ the concepts by assuming that the long-run conventional money demand function is as follows:

$$m_t = F(p_t, y_t, R_t) + \epsilon_t, \quad F_p, F_y > 0, \text{ and } F_R < 0 \qquad (1)$$

where

$m_t$ = the narrow nominal money stock/supply (M1)
$p_t$ = the price level measured by the consumer price index (CPI)
$y_t$ = the real income measured by the gross domestic product (GDP)
$R_t$ = the nominal interest rates
$\epsilon_t$ = the error term with white noise innovations

Small case letters denote logarithmic form of the variables, and subscript t denotes time period. The information set $\Lambda$ includes $R_t$, period average of foreign exchange rates ($xr_t$), foreign exchange risk ($\sigma^2_t$), other important current variables, and past information on all relevant variables in the entire model.

Suppose equation (1) can be expressed to have the following normal distribution:

$$\begin{bmatrix} m_t \\ p_t \\ y_t \end{bmatrix} / \Lambda \sim N\left( \begin{bmatrix} \mu^m{}_t \\ \mu^p{}_t \\ \mu^y{}_t \end{bmatrix}, \begin{bmatrix} \sigma^{mm}{}_t & \sigma^{mp}{}_t & \sigma^{my}{}_t \\ \sigma^{pm}{}_t & \sigma^{pp}{}_t & \sigma^{py}{}_t \\ \sigma^{ym}{}_t & \sigma^{yp}{}_t & \sigma^{yy}{}_t \end{bmatrix} \right) = N(\mu, \Sigma) \qquad (2)$$

where every mean ($\mu$) and covariances ($\Sigma$) are conditioned on information set $\Lambda$.

Our money demand function given in equation (1) conditions nominal money stock on prices, real income and other relevant information. Thus we have

$$m_t/z_t, \Lambda_t \sim N[\mu^m{}_t + \delta_t(z_t - \mu^z{}_t), \zeta_t] \qquad (3)$$

where $z_t = (p_t, y_t)$, $\delta_t = \sigma^{mz}{}_t/\sigma^{zz}{}_t$, and $\zeta_t = \sigma^{mm}{}_t - (\sigma^{mz}{}_t)^2/\sigma^{zz}{}_t$. The regression coefficient of $m_t$ on $z_t$ is conditioned on $\Lambda_t$, with $\zeta_t$ as the conditional variance.

To obtain an equation that relates the conditional means of $m_t$ on $z_t$ to a set of variables $x_t \in \Lambda_t$, with our parameters of interest given as $\beta$ and $\gamma$, our money demand function can be expressed as

$$\mu^m{}_t = \beta\mu^z{}_t + \gamma x_t \qquad (4)$$

where the function is in logarithmic form, and $x_t$ includes other relevant explanatory variables that express money demand behaviour in the two countries under study, and $\beta$ which is the parameters of interest is a function of marginal density of $z_t$ which is denoted by $\lambda_{2t}$.

Now by substituting equation (4) into (3), and arranging to obtain the conditional distribution of $m_t$ on $z_t$ we arrive at the following conditional equation:

$$\begin{aligned} m_t/z_t, \Lambda_t &\sim N[\beta_t\mu^z_t + \gamma_t x_t + \delta_t(z_t - \mu^z_t), \zeta_t] \\ &= N[\beta_t z_t + \gamma_t x_t + (\delta_t - \beta_t)\{z_t - \mu^z_t\}, \zeta_t] \end{aligned} \qquad (5)$$

For an appropriate regression analysis of $m_t/z_t,\Lambda_t$ that can be used for policy recommendations, $z_t$ must meet both weak- and super-exogeneity properties.

Following Engle and Hendry (1993, p.124), equation 5 can be efficiently estimated if and only if $\beta_t(\lambda_{2t}) = \delta_t$, which implies that $\mu^z_t$, and $\sigma^{zz}_t$ are excluded from the conditional model. Thus z becomes weak-exogenous for the parameters of interest $\beta$ and $\gamma$. In addition to $z_t$ being weak-exogenous, the regression coefficients $\delta_t$ of $z_t$ in equation (3) must be constant such that $\delta_t = \delta\ \forall t$. This condition implies also that the covariances are constant such that $\zeta_t = \zeta\ \forall t$, if $\sigma^{mm}_t = \zeta + \delta\sigma^{zz}_t$. In this study, we have assumed homoscedasticity process to simplify the analysis, although heteroscedasticity process can also be used for the test with some difficulty. See Engle and Hendry (1993).

The super-exogeneity condition of $z_t$ is satisfied if $z_t$ is weak-exogenous, has constant regression coefficients ($\delta$), and finally has invariance parameters of interest ($\beta_t$) with respect to policy changes ($\lambda_{2t}$). Note that if the parameters of interest are invariant, then although the parameters of interests can vary with time, their variations would be independent of any variations in the marginal density of $x_t$ ($\lambda_{2t}$), meaning that there shall be complete absence of cross-restrictions.

In the empirical analysis following, we have used the methods of Wu (1973) and Hausman (1978), and Engle and Granger's (1987) to test for weak-exogeneity of price and real income conditioned on the nominal money stock. Chow's stability and predictive adequacy tests are used to establish the stability of the regression coefficients. The structural invariance of the model which basically involves the ability of the model to predict beyond the sample range of estimation is tested by Brown et al.'s (1975) recursive regression estimates.

## Data Source(s)

The main source of data is various issues of International Financial Statistics published by the International Monetary Fund. The quarterly data of the GDP is generated from its annual series. See Diz (1970).

## III. Discussion of the Estimated Results

The stationarity properties of the variables are tested by the generalized least squares (GLS) estimates from a response surface regression which relate the critical values to the sample sizes. See MacKinnon (1991). The unit root test results are reported in Table 1.1. The results of the Dickey-Fuller (DF) and augmented DF (ADF) tests with lag-length of four indicate that with the exception of the level form exchange rates in Barbados, none of the level form variables are significant at a 0.05 level for both

### Table 1.1: Univariate Unit Root Tests, 1962.1-1995.3†

| | Barbados With Trend | | Jamaica | | Barbados Without Trend | | Jamaica | |
|---|---|---|---|---|---|---|---|---|
| Vars. | DF | ADF,4 | DF | ADF,4 | DF | ADF,4 | DF | ADF,4 |
| m | -1.33 | -0.82 | -0.46 | -0.64 | -1.48 | -2.23 | 2.47 | 2.01 |
| y | -0.69 | -1.38 | -1.06 | -1.65 | -4.42 | -3.65 | -1.09 | -1.54 |
| p | -2.27 | -3.61 | -0.22 | -1.06 | -6.63 | -3.74 | 6.28 | 2.15 |
| r | -2.03 | -3.02 | -2.20 | -1.43 | -1.99 | -2.98 | 0.10 | 1.05 |
| xr | -6.94 | -4.27 | -1.13 | -2.04 | -7.11 | -4.47 | 1.77 | 0.28 |
| $\sigma^2$ | --- | --- | 0.79 | -3.00 | --- | --- | 1.68 | -2.73 |
| $\Delta m$ | -9.73 | -4.21 | -11.6 | -5.01 | -9.32 | -3.24 | -11.0 | -4.29 |
| $\Delta y$ | -5.54 | -3.93 | -7.12 | -3.17 | -4.63 | -2.66 | -7.14 | -3.20 |
| $\Delta p$ | -8.18 | -3.47 | -5.02 | -4.19 | -8.00 | -3.13 | -4.16 | -3.21 |
| $\Delta r$ | -5.43 | -5.11 | -7.47 | -7.23 | -5.46 | -5.14 | -7.49 | -7.01 |
| $\Delta xr$ | 10.51 | -4.54 | -7.44 | -4.33 | 10.43 | -4.43 | -7.28 | -4.13 |
| $\Delta\sigma^2$ | --- | --- | -5.97 | -3.98 | --- | --- | -5.89 | -3.78 |

**Notes:** The first difference operator is represented by $\Delta$. All of the variables (Vars.) except $xr_t$ in Barbados are integrated of degree unity I(1). The absolute form of McKinnon's 95 percent confidence values obtained from surface response GLS estimates for the Dickey-Fuller (DF) and augmented DF (ADF) are 3.4 and 2.9 respectively.

The fourth order ADF test statistic is given by the t-ratio of $n_2$ in the ADF regression with trend

$$\Delta h_t = \varphi_0 + \varphi_1 t + \varphi_2 h_{t-1} + \Sigma\kappa_j \Delta h_{t-j} + v_t, \ \forall j \in [1,4]$$

The DF test is achieved by setting $\kappa_j$s $= 0$ so that there are no augmentations, and the DF and ADF tests without trend is achieved by setting $\varphi_1 = 0$. The t-ratio of $\varphi_2$ if it is negative and significant implies that there are no unit root in $h_t$.

† The sample size of Barbados spans 1972.1 to 1995.3.

cases with and without trend in both Barbados and Jamaica. However, all of the first difference form of the variables are significant at a 0.05 level for both cases with and without trend in both countries.

The results of the exchange rates indicate that the foreign exchange market is weak-form inefficient in Barbados, but weak-form efficient in Jamaica as the level form of the exchange rates are stationary in Barbados while exhibiting random walk behaviour in Jamaica. Thus, the long-run money demand function of Jamaica addresses currency substitution which is captured by the nominal exchange rate, and foreign exchange risk, two important developments following the global liberalization of the foreign exchange markets (FEM), while the Barbadian long-run money demand function does not address similar issues because of the weak-form inefficiency of the FEM due to the fixed foreign exchange rate regime adopted by the country since 1977.

## The Error Correction Model

The general formulation of the conditional process of the error correction model (ECM) of the money demand function is

$$\Delta m_t = \eta_0(L)\Delta p_t + \eta_1(L)\Delta y_t + \eta_2(L)\Delta r_t + \eta_3(L)\Delta xr_t + \eta_4(L)\Delta\sigma^2_t + \tau_0 + \tau_1 EC_{t-1} + \tau_2 s1 + \tau_3 s2 + \tau_4 s4 + \xi_t \qquad (6)$$

where

$EC_{t-1} = m_t - \alpha_0 - \alpha_1 p_t - \alpha_2 y_t - \alpha_3 r_t - \alpha_4 xr_t - \alpha_5 \sigma^2_t$, L denotes a lag operator such that $Ly_t = y_{t-1}$, and $L^n y_t = y_{t-n}$. The error correction term ($EC_t$) above is used for Jamaica with $\tau_2 = \tau_3 = 0$, while the restrictions $\alpha_1 = \alpha_2 = 1$, and $\alpha_3 = \alpha_4 = \alpha_5 = 0$ are imposed for

Barbados with $\tau_4 = 0$. The a priori expectations are as follows: $\eta_0(1)$ and $\eta_1(1) \geq 0$, and $\eta_2(1)$ and $\eta_3 \leq 0$. The rest of the parameters can assume any signs and still be plausible and consistent with economic theory. For a dynamic stability and cointegration, $-1 \leq \tau_1 < 0$. The lag lengths of the polynomials are restricted to a maximum of four because the study employs quarterly series.

The results of the ECM derived from Hendry's general-to-specific modelling procedure are reported in Table 2 for change in nominal money stock ($\Delta m_t$), and inverted equations for changes in price ($\Delta p_t$) and real income ($\Delta y_t$). All a priori expectations hold true as specified in equation (6). The significance of the coefficients of $EC_{t-1}$ term confirm the existence of cointegration in both Barbados and Jamaica. See Engle and Granger (1987), and Banerjee et al. (1993).

The OLS estimation results of the ECM of the conditional money demand function in both countries are robust and have signs that conform to a priori expectations. There are no serial correlation and heteroscedasticity problems, and the functional forms are well specified and normal. White's (1980) test for general forms of heteroscedasticity which require no specification of the nature of the heteroscedasticity is used.[3] The adjusted coefficients of determination ($R^2$) are greater than the Durbin-Watson (DW) statistics which lend credence to the absence of spurious results.

The coefficients of $EC_{t-1}$ in the change in money demand of the conditional process are -0.22 and -0.20 in Barbados and Jamaica respectively, an indication of relatively slow adjustment, and they are both significant at a 0.05 level. These results compare favourably with the studies of other countries while contrasting sharply with Craigwell's (1991) results in Jamaica which ranges from about negative sixty-five percent to ninety-five percent. See Domowitz and Elbadawi (1987, pp.264, 266), and Huang (1994).[4]

## THE EXOGENEITY TEST

Weak-exogeneity of price and real income is tested by examining the coefficients of $EC_{t-1}$ in the inverted price and real income equations derived from the conditional money demand ECM of equation (6). The results reported in Table 1.2 in both countries show that the coefficients of $EC_{t-1}$ in both inverted changes in price and real income equations have the wrong signs, although both inverted equations are significant and maintained satisfactory functional forms.

The results of the estimates signalled mild heteroscedasticity but severe serial correlation problems. As a results, we employed dynamic OLS (DOLS) technique developed by Newey and West (1987) which uses adjusted standard errors with twelve truncation lags and Parzen's weight to resolve both the serial correlation and heteroscedasticity problems. The t-ratios reported in Table 1.2 for $\Delta p_t$ and $\Delta y_t$ are adjusted to correct for both serial correlation and heteroscedastcity problems. It is clear from the results in Table 1.2 that the inverted changes in price and real income equations are not cointegrated, while the changes in money demand equation is. Thus confirming that neither price nor real income are endogenous in both countries. See Engle and Granger (1987).

**TABLE 1.2: OLS ESTIMATES OF THE ECM OF $\Delta m_t$ AND INVERTED EQUATIONS $\Delta p_t$ AND $\Delta y_t$.**

| | Barbados | | | Jamaica | | |
|---|---|---|---|---|---|---|
| Regres. | $\Delta m_t$ | $\Delta p_t$ | $\Delta y_t$ | $\Delta m_t$ | $\Delta p_t$ | $\Delta y_t$ |
| Const. | -0.448 | 6.219 | 0.216 | -0.023 | 0.034 | 0.024 |
| | [3.193] | [1.351] | [2.815] | [2.146] | [14.895] | [9.355] |
| $\Delta p_t$ | 0.006 | | -0.008 | 1.014 | | -0.630 |
| | [1.723] | | [4.464] | [4.237] | | [11.05] |
| $\Delta y_t$ | 0.454 | -26.378 | | 0.908 | -0.804 | |
| | [2.199] | [4.464] | | [3.269] | [11.05] | |
| $\Delta m_t$ | | 6.045 | 0.132 | | 0.129 | 0.091 |
| | | [1.723] | [2.199] | | [4.237] | [3.269] |
| $\Delta xr_t$ | | | | -0.146 | 0.121 | 0.048 |
| | | | | [2.046] | [5.141] | [2.139] |
| $\Delta r_t$ | -0.009 | 0.240 | 0.003 | -0.007 | 0.008 | -0.001 |
| | [1.478] | [1.265] | [1.011] | [2.676] | [0.872] | [0.107] |
| $\Delta \sigma^2_t$ | | | | 0.002 | 0.006 | 0.002 |
| | | | | [2.682] | [2.495] | [1.030] |
| $EC_{t-1}$ | -0.220 | 1.998 | 0.101 | -0.202 | 0.071 | 0.057 |
| | [3.101] | [0.854] | [2.611] | [3.758] | [3.702] | [3.327] |
| s4 | | | | 0.107 | -0.010 | -0.005 |
| | | | | [8.665] | [1.772] | [0.979] |
| s2 | 0.034 | -0.461 | -0.004 | | | |
| | [2.225] | [0.948] | [0.526] | | | |
| s1 | 0.064 | -1.294 | 0.002 | | | |
| | [3.906] | [2.394] | [0.249] | | | |
| $\chi^2_{SC}(4)$ | 0.227 | 6.993 | 8.347 | 1.840 | 58.889 | 41.716 |
| $\chi^2_{FF}(1)$ | 0.010 | 0.551 | 1.732 | 0.054 | 1.396 | 7.457 |
| $\chi^2_{N}(2)$ | 3.717 | 3.285 | 57.252 | 0.022 | 20.225 | 2.782 |
| $\chi^2_{H}(1)$ | 1.168 | 0.238 | 10.190 | 0.137 | 0.737 | 34.166 |
| $\chi^2_{SIV}(1)$ | | | | | | |
| $R^2$ | 0.270 | 0.23 | 0.268 | 0.498 | 0.711 | 0.539 |
| DW | 1.978 | 1.516 | 1.300 | 1.868 | 0.931 | 1.047 |
| RSS | 0.242 | 235.442 | 0.070 | 0.402 | 0.051 | 0.040 |

**Notes:** Lagrange multiplier test of residual serial correlation is $\chi^2_{SC}$, Ramsey reset test of functional form using the square of fitted values is $\chi^2_{FF}$, normality test based on skewness and kurtosis of residuals is $\chi^2_{N}$, heteroscedasticty test based on the regression of squared residuals of squared fitted values is $\chi^2_{H}$, RSS is the residual sum of squares, s1, s2, and s4 are seasonal dummies for the first, second and fourth quarters respectively. The t-ratios and degrees of freedom are in the square brackets and parentheses respectively.

We have also employed the method of Wu (1973) and Hausman (1978) to test for weak-exogeneity, and power of exogeneity of price and real income conditional in ECM of $\Delta m_t$. The instruments for estimating $\Delta p_t$ are $\Delta p_{t-2}$, $\Delta m_{t-1}$, $\Delta r_{t-1}$, s1 and s2, and that of estimating $\Delta y_t$ are $\Delta y_{t-1}$, $\Delta r_{t-1}$, $\Delta m_{t-1}$, $\Delta y_{t-3}$, s2 and s1 in Barbados. In the case of Jamaica, the instruments for estimating $\Delta p_t$ and $\Delta y_t$ are $\Delta p_{t-1}$, $\Delta p_{t-2}$, $\Delta y_{t-1}$, $\Delta y_{t-2}$, $\Delta m_{t-1}$, $\Delta m_{t-2}$, and s4. The residuals calculated from the regression equations $\Delta p_t$ and $\Delta y_t$ above are $\Delta p_{\epsilon t}$ and $\Delta y_{\epsilon t}$ respectively for both countries. The results of the estimates of the ECM of $\Delta m_t$ with joint test of zero restrictions on the coefficients of $\Delta p_{\epsilon t}$ and $\Delta y_{\epsilon t}$ as measured by the LM-test, LR-test, and F-test are reported in Table 1.3. The joint test of restrictions on the coefficients of $\Delta p_{\epsilon t}$ and $\Delta y_{\epsilon t}$ in the ECM of $\Delta m_t$ are insignificant in both countries. Thus indicating that both price and real income are weak-exogenous in both countries.

The power of weak exogeneity was tested by replacing $\Delta p_t$ and $\Delta y_t$ of the conditional equation of $\Delta m_t$ in both countries by $\Delta p_{\epsilon t}$ and $\Delta y_{\epsilon t}$, respectively. The results of the t-ratios reported in Table 1.3 show that the coefficients of $\Delta p_{\epsilon t}$ and $\Delta y_{\epsilon t}$ are significant at a 0.05 level in Jamaica, and at a 0.10 level in Barbados. Thus confirming that the exogeneity tests have power in both countries.

## Comprehensive Stability and Super-Exogeneity Tests

The stability of both parameters and equations are crucial in formulating and implementing macro-economic policies, particularly for small island economies that underwent drastic structural, economic and political changes in the mid 1970s, late 1980s and early 1990s.

**TABLE 1.3: WEAK-EXOGENEITY AND POWER OF EXOGENEITY TEST RESULTS OF $\Delta p_t$ AND $\Delta y_t$ CONDITIONAL ON $\Delta m_t$**

| | Weak-Exogeneity | | Power of Exogeneity | |
|---|---|---|---|---|
| Variables | Barbados | Jamaica | Barbados | Jamaica |
| $\Delta p_t$ | -0.004 | 0.901 | | |
| | [0.382] | [3.542] | | |
| $\Delta y_t$ | 0.750 | 0.402 | | |
| | [1.352] | [0.687] | | |
| $\Delta r_t$ | -0.005 | -0.007 | -0.008 | -0.007 |
| | [0.730] | [2.753] | [1.324] | [2.597] |
| $\Delta xr_t$ | | -0.146 | | -0.067 |
| | | [1.981] | | [0.923] |
| $\Delta\sigma^2_t$ | | 0.002 | | 0.003 |
| | | [2.575] | | [4.240] |
| $EC_{t-1}$ | -0.204 | -0.192 | -0.209 | -0.152 |
| | [2.839] | [3.506] | [2.914] | [2.765] |
| s4 | | 0.105 | | 0.110 |
| | | [8.171] | | [8.433] |
| s2 | 0.029 | | 0.033 | |
| | [1.920] | | [2.190] | |
| s1 | 0.042 | | 0.065 | |
| | [1.926] | | [4.190] | |
| $\Delta p_{\epsilon t}$ | 0.012 | 0.448 | 0.007 | 0.865 |
| | [0.980] | [1.216] | [1.907] | [2.364] |
| $\Delta y_{\epsilon t}$ | -0.374 | 0.784 | 0.394 | 0.753 |
| | [0.624] | [1.225] | [1.757] | [2.262] |
| intercepts | -0.390 | -0.015 | -0.413 | 0.016 |
| | [2.666] | [1.274] | [2.923] | [2.379] |
| $R^2$ | 0.270 | 0.498 | 0.260 | 0.450 |
| DW | 1.859 | 1.894 | 1.905 | 1.793 |
| $\chi^2_{SC}(4)$ | 1.515 | 1.875 | 0.621 | 2.362 |
| $\chi^2_{FF}(1)$ | 0.000 | 0.255 | 0.287 | 0.560 |
| $\chi^2_{N}(1)$ | 4.873 | 0.185 | 3.043 | 1.100 |
| $\chi^2_{H}(1)$ | 1.504 | 0.211 | 1.426 | 0.018 |
| Joint test of zero restrictions on the coefficients of additional variables. | | | | |
| $\chi^2_{LM}(2)$ | 2.381 | 2.313 | | |
| $\chi^2_{LR}(2)$ | 2.416 | 2.334 | | |
| F | 1.093 | 1.085 | | |

**Notes:** See Table 1.2.

We have employed both Chow's (1960) test which is more powerful if the date of the structural break is known, and Brown et al.'s (1975) structural stability test which is based on the ability of the model to predict outside the sample range of estimation. In the Chow test, we have used two dates to split the sample size in both countries.

In Jamaica, we used 1977 which marked the date of the adoption of the IMF policies, and 1989 which marked the end of Edward Seaga's decade of JLP government, and the return of Michael Manley's PNP to power when the country adopted a full-fledged World Bank and IMF's liberalization and privatization policies. In Barbados, we used 1986 and 1990 as the strucural break points. The 1986 marked the inception of the government of Erskine Sandiford's Democratic Labour Party (DLP) to power, and the reformation of taxes with income earners below BD$15000 being exempted from income tax payment, while 1990 was the first time that the government's current account registered a deficit of B$6.9 million. During this period, the Barbadian economy performed poorly, with the major export earning sectors, namely: sugar, manufacturing, and tourism faring worst. See Downes (1994). Additionally, there was a severe short-fall in foreign exchange in the country which was resolved by rationing foreign exchange among banks with the Central Banks adopting a hands-off position.

The Chow tests of stability of the regression coefficients of the conditional ECM of equation $\Delta m_t$ in Barbados are $F(7, 69) = 1.466$ over the period 1974.1-1986.4, and $F(7, 69) = 1.095$ over the period 1974.1-1990.4, and in Jamaica are $F(8, 111) = 0.904$ over the period 1962.2-1989.4, and $F(8, 111) = 1.414$

over the period 1962.2-1977.4, and neither can be rejected even at a 0.10 significant level. Thus, the results firmly indicate that the regression coefficients are stable.

The goodness-of-fit of the ECM of equation $\Delta m_t$ in both countries are tested further by employing out-of-sample forecasting performance as a criterion. The adequacy of prediction tests are $F(16, 103) = 1.244$ using sixteen observations covering 1990.1-1993.4, and $F(64, 55) = 1.444$ using sixty-four observations covering 1978.1-1993.4 in Jamaica. In Barbados, the results are $F(31, 45) = 0.762$ covering the period 1987.1-1994.3, and $F(15, 61) = 0.820$ covering the period 1991.1-1994.3. In both countries the null hypothesis of adequate prediction cannot be rejected even at a 0.10 significant level.

The root mean sum of squares of predictive errors are 0.074 from 1990.1-1993.4, and 0.263 from 1978.1-1993.4 in Jamaica; and 0.060 from 1987.1-1994.3, and 0.058 from 1991.1-1994.3 in Barbados. Thus the out-of-sample forecasting performance of the model in both countries are excellent.

The structural stability of both equations and parameters have been tested by using two different dates to split the sample sizes in both countries. However, it is possible that other dates could be used as well as structural break points. For instance, 1973 and 1978 which were marked by the price hikes of the Oil and Petroleum Exporting Countries (OPEC), and short-fall in agricultural products world-wide due to poor weather which resulted in internationally transmitted inflation could be used as 'structural' break points.[5] Notwithstanding the different impact of the international transmitted inflation, and natural disasters that had plagued the region over the years such as Hurricane Gilbert in 1988, we decided to use an alternative stability tests for the study which do not require a definite knowledge of specific dates when structural break occurred, namely: the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) tests of structural stability. We have reported the CUSUMSQ test of recursive residuals in both countries by plotting it against time because it is more robust. See Figures 1.1 and 1.2. All of the figures are reported in the Appendix. In both countries, the CUSUMSQ of equation $\Delta m_t$ are within the 95 percent boundaries, which mean that there are neither systematic changes nor sudden departures from constancy of the regression coefficients. The CUSUMSQ test of inverted equation $\Delta p_t$ shown in Figures 1.3 and 1.4 for Barbados and Jamaica respectively, and that of inverted equation $\Delta y_t$ shown in Figures 1.5 and 1.6 for Barbados and Jamaica respectively are unstable. Thus inverted equations $\Delta p_t$ and $\Delta y_t$ exhibit systematic changes and sudden departures from constancy of the regression coefficients.

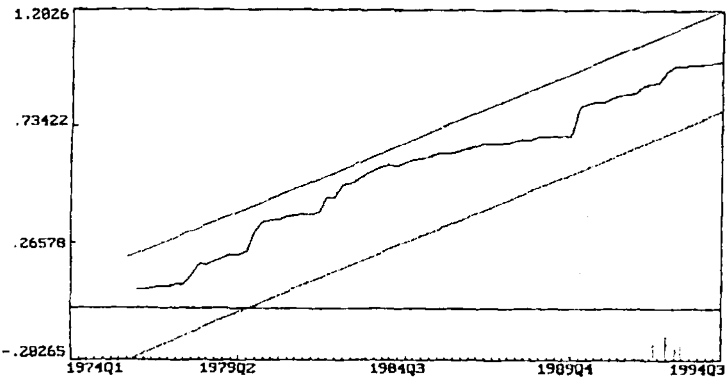
The ECM of the conditional equation $\Delta m_t$ is used to establish super-exogeneity conditions of $\Delta p_t$ and $\Delta y_t$ by recursively estimating the coefficients on $\Delta p_t$ and $\Delta y_t$ in equation $\Delta m_t$ in both countries. See Figures 1.7 and 1.8 for Barbados and Jamaica respectively on $\Delta p_t$, and Figures 1.9 and 1.10 for Barbados and Jamaica respectively on $\Delta y_t$. It is clear from Figures 1.7, 1.8, 1.9 and 1.10 that the coefficients of the recursive estimates of regressors $\Delta p_t$ and $\Delta y_t$ are stable.

The recursive estimation of the coefficients on $\Delta m_t$ in the inverted models for $\Delta p_t$ and $\Delta y_t$ in Barbados are in Figures 1.11 and 1.12 respectively, while in Jamaica the same recursive coefficients of

$\Delta m_t$ in the inverted models for $\Delta p_t$ and $\Delta y_t$ are in Figures 1.13 and 1.14 respectively. In all cases for both countries, the recursive coefficients on $\Delta m_t$ are unstable. This means that the conditional ECMs of $\Delta m_t$ are structurally invariant.

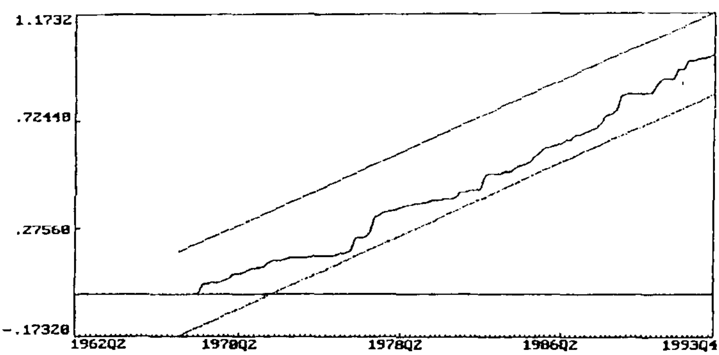
For further validation of the structural invariance of the conditional ECM of $\Delta m_t$ relative to inverted equations $\Delta p_t$ and $\Delta y_t$, we used 1990 and 1989 as the terminal years for the estimation for Barbados and Jamaica respectively. The out-of-sample predictive adequacy tests which are used to test structural invariance for inverted equation $\Delta p_t$ are $F(15, 61) = 2.267$ over 1991.1-1994.3 for Barbados, and $F(16, 104) = 6.536$ over 1990.1-1993.4 for Jamaica, while similar tests for inverted equation $\Delta y_t$ are $F(15, 61) = 4.730$ for Barbados, and $F(16, 104) = 3.571$ for Jamaica. In all cases for both countries, the out-of-sample predictive adequacy tests are rejected at a 0.01 significant level. Thus the empirical tests confirm clearly that price and real income are super-exogenous in the conditional ECM of $\Delta m_t$ for both countries.

**FIGURE 1.1: THE CUSUMSQ OF RECURSIVE RESIDUALS OF ECM OF EQN. ΔM FOR BARBADOS**



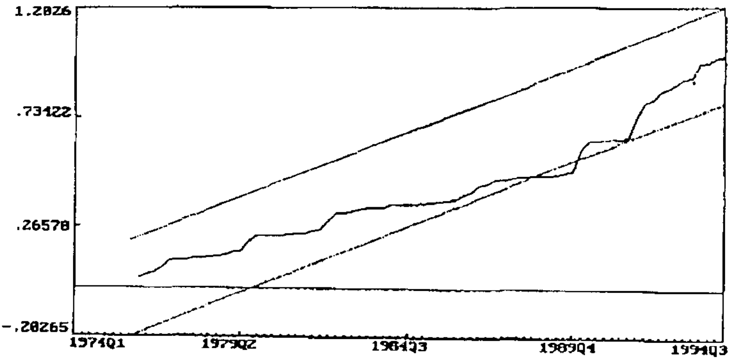

The straight lines represent critical bounds at 5% significant Level.

**FIGURE 1.2: THE CUSUMSQ OF RECURSIVE RESIDUALS OF ECM OF EQN. ΔM FOR JAMAICA**



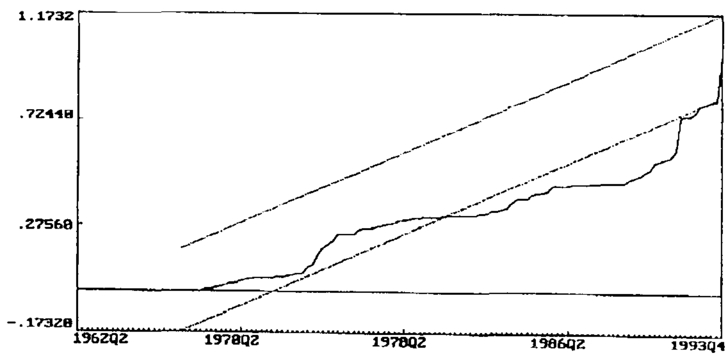

The straight lines represent critical bounds at 5% significant Level.

**FIGURE 1.3: THE CUSUMSQ OF RECURSIVE RESIDUALS OF ECM OF EQN. ΔP FOR BARBADOS**



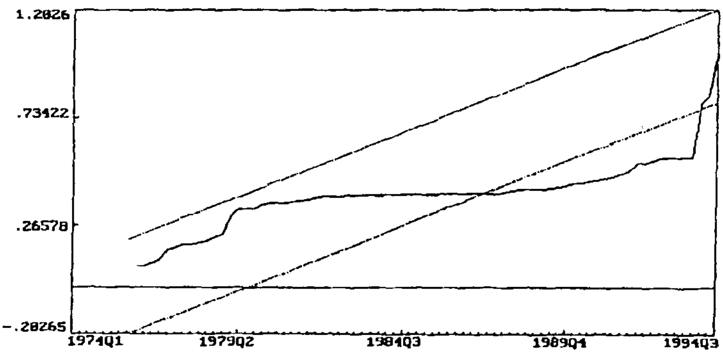

The straight lines represent critical bounds at 5% significant Level.

**FIGURE 1.4: THE CUSUMSQ OF RECURSIVE RESIDUALS OF ECM OF EQN. ΔP FOR JAMAICA**



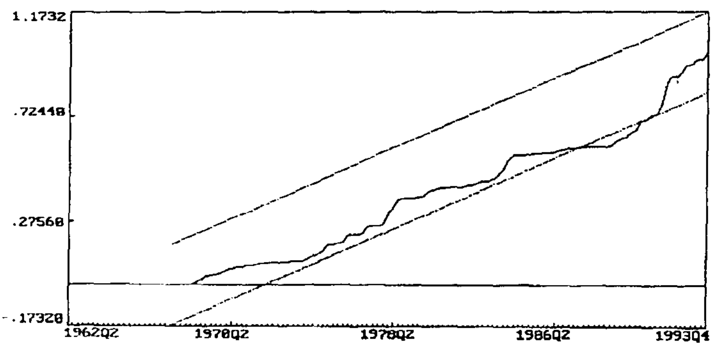

The straight lines represent critical bounds at 5% significant Level.

**FIGURE 1.5: THE CUSUMSQ OF RECURSIVE RESIDUALS OF ECM OF EQN. ΔY FOR BARBADOS**




The straight lines represent critical bounds at 5% significant Level.

**FIGURE 1.6: THE CUSUMSQ OF RECURSIVE RESIDUALS OF ECM OF EQN. ΔY FOR JAMAICA**




The straight lines represent critical bounds at 5% significant Level.

FIGURE 1.7: THE COEFFICIENT OF ΔP IN ECM OF THE CONDITIONAL MONEY DEMAND EQUATION AND ITS 2 STANDARD ERRORS (S.E.) BANDS BASED ON RECURSIVE OLS FOR BARBADOS

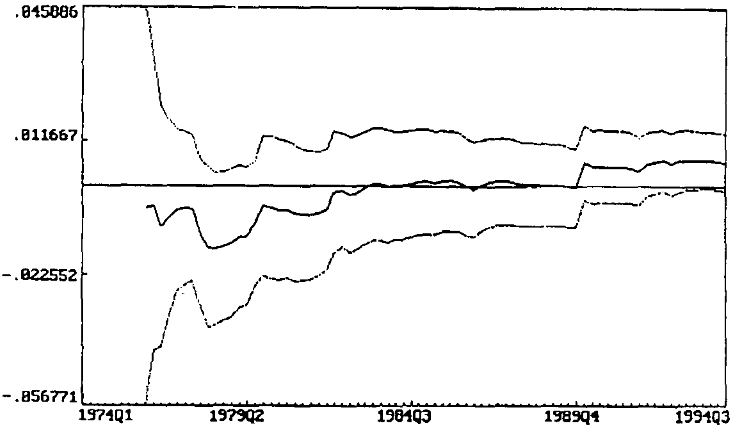



FIGURE 1.8: THE COEFFICIENT OF ΔP IN ECM OF THE CONDITIONAL MONEY DEMAND EQUATION AND ITS 2 STANDARD ERRORS (S.E.) BANDS BASED ON RECURSIVE OLS FOR JAMAICA

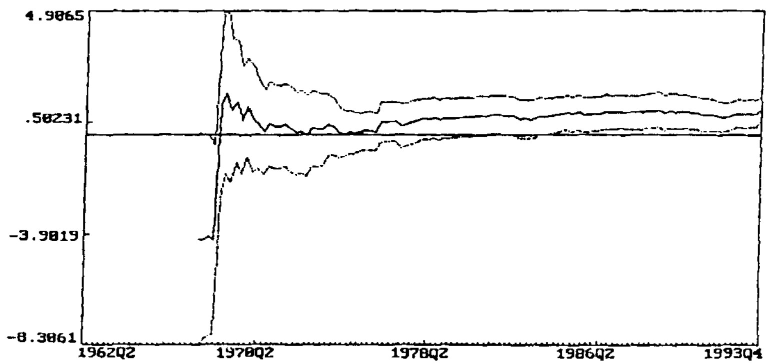


FIGURE 1.9: THE COEFFICIENT OF $\Delta Y$ IN ECM OF THE CONDITIONAL MONEY DEMAND EQUATION AND ITS 2 STANDARD ERRORS (S.E.) BANDS BASED ON RECURSIVE OLS FOR BARBADOS

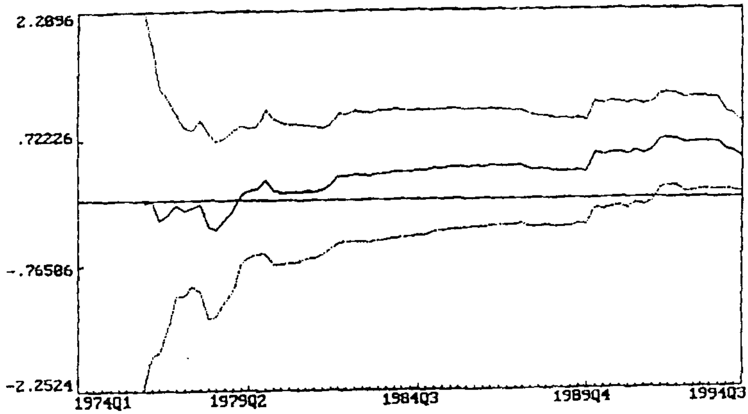



FIGURE 1.10: THE COEFFICIENT OF $\Delta Y$ IN ECM OF THE CONDITIONAL MONEY DEMAND EQUATION AND ITS 2 STANDARD ERRORS (S.E.) BANDS BASED ON RECURSIVE OLS FOR JAMAICA

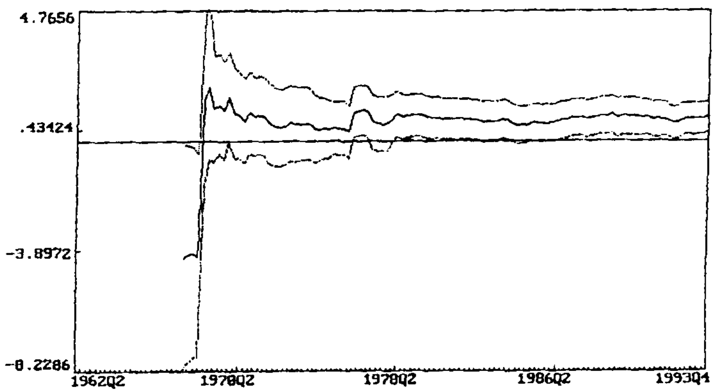


**Figure 1.11: The Coefficient of ΔM in Inverted Equation of ΔP and its 2 (S.E.) Bands Based on Recursive OLS for Barbados**

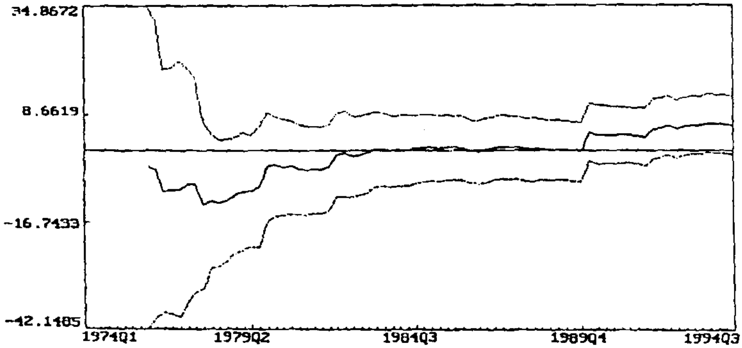



**Figure 1.12: The Coefficient of ΔM in Inverted Equation of ΔY and its 2 (S.E.) Bands Based on Recursive OLS for Barbados**

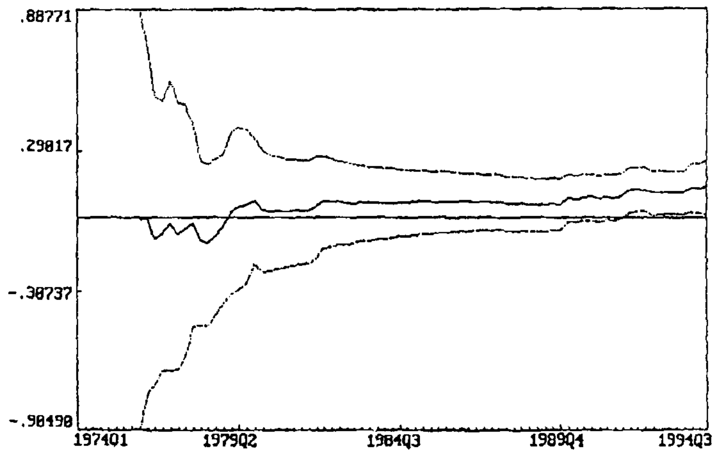


FIGURE 1.13: THE COEFFICIENT OF ΔM IN INVERTED EQUATION OF ΔP AND ITS 2 (S.E.) BANDS BASED ON RECURSIVE OLS FOR JAMAICA

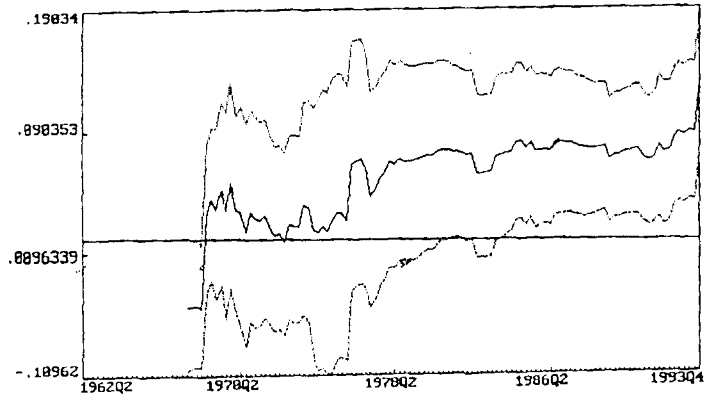
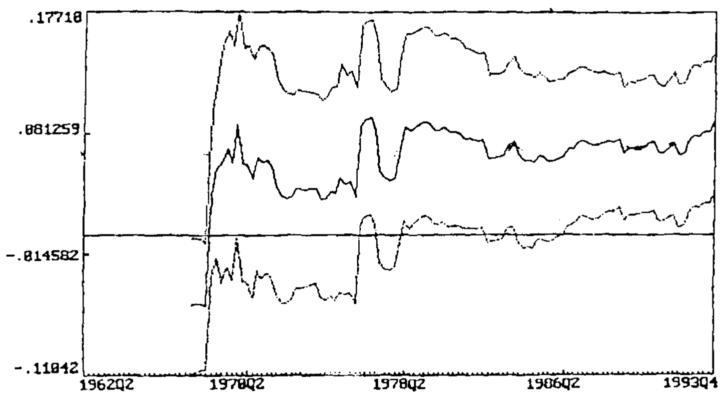



FIGURE 1.14: THE COEFFICIENT OF ΔM IN INVERTED EQUATION OF ΔY AND ITS 2 (S.E.) BANDS BASED ON RECURSIVE OLS FOR JAMAICA



## III. Conclusion

The class of conditional ECMs of money demand are well estimated for both countries as evidenced by the insignificant functional form and normality tests. There are no serial correlation and heteroscedasticity problems in Jamaica, while in Barbados the Newey and West's (1987) DOLS is used to correct both serial correlation and heteroscedasticity problems.

The DF and ADF tests clearly signal that the level form foreign exchange rates are stationary in Barbados, while exhibiting random walk behaviour in Jamaica. Thus, the FEM is weak-form inefficient in Barbados, and weak-form efficient in Jamaica.

The methods of Wu (1973), Hausman (1978), and Engle and Granger (1989) tests show price and real income to be weak-form exogeneous in the conditional ECM of money demand in both countries. However, the power of exogeneity is stronger in Jamaica than Barbados as evidenced by their different significance levels.

The CUSUM and CUSUMSQ tests of recursive residuals indicate that the parameters of the conditional ECM of money demand are stable or 'constant' in both countries, although only the CUSUMSQ tests are reported in the study. Additionally, the out-of-sample predictive adequacy tests also confirm that the ECM of $\Delta m_t$ in both countries are structurally invariant.

Further tests from the estimated recursive coefficients of $\Delta p_t$ and $\Delta y_t$ in the conditional ECM of $\Delta m_t$ show that the parameters are stable relative to the estimated recursive coefficients of $\Delta m_t$ in the inverted equations $\Delta p_t$ and $\Delta y_t$ respectively for both countries. However, the results are more robust for Jamaica than Barbados. Thus the structural invariance of the conditional ECM of money demand is more definitive for Jamaica than Barbados. Notwithstanding, we can safely conclude that real income and price in the conditional money demand functions in both countries are weak-form exogenous, and have power. The conditional ECM of money demand in both countries also have structurally invariant parameters. Finally, real income and prices are super-exogenous in both countries, especially for Jamaica. The class of conditional ECMs of money demand obtained in both countries can be relied upon for monetary policy and forecasting.

## Notes

1. Here changes in the money supply is endogenous and is solely caused by changes in aggregate output. See Tobin (1970).

2. Bourne (1974) and Howard (1980) used simultaneous equation estimating techniques in their studies for Jamaica and Guyana respectively.

3. Craigwell (1991, p.29) could not use the general form of White's (1980) heteroscedasticity test because his data sample was under-sized. For Craigwell's method see Domowitz and Elbadawi (1987, p.265).

4. Engle and Hendry (1993, pp.133, 136) obtained $EC_{t-1}$ term with coefficients that ranges from -0.10 to -0.08 for similar studies in the U.K.

5. We note though that it has been argued elsewhere that Barbados weathered the ill-effects of the international transmitted inflation by adopting appropriate economic policies during the 1970s. See Worrel (1996).

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# CHAPTER 2

# THE GARCH AND VOLUME RELATIONSHIP WITH HETEROSCEDASTICITY IN STOCK RETURNS ON THE JAMAICA STOCK EXCHANGE

*Jacqueline Hamilton*

# The GARCH and Volume Relationship with Heteroscedasticity in Stock Returns on the Jamaica Stock Exchange

*Jacqueline Hamilton*

*The author would like to thank Sang Kim for valuable comments and guidance through this work. Without the computer program provided by him estimation of the model would have been very difficult.*

## Introduction

The validity of using Generalized Autoregressive Conditional Heteroscedasticity (GARCH), in modeling the conditional variances in stock returns is well established (Bollerslev, Chou and Kroner, 1992). Research has been conducted to show the presence of the ARCH effect (Lamourex and Lastrapes 1990), as well as to suggest possible explanation for its presence (Tauchen and Pitts 1983).

Extensive research in developed stock markets reveal the uncertainty of speculative stock prices, measured by the changing variance over time. Engle (1982), introduced the Autoregressive Conditional Heteroscedasticity (ARCH) processes, which has been used extensively in the modeling of the variation in stock prices. Bollerslev (1986), extended the ARCH process to depend also on past conditional variances.

ARCH models the time variation in prices, but provides no theoretical explanation regarding the cause of such variation. It informs that there is some factor or set of factors which impact on prices, causing its variance to change over time, but does not specify what these factors are. Porterba and Summers (1986) explains that shocks which cause variations in prices had to persist for long periods of time in order to explain the large fluctuations observed in developed stock markets. If shocks are transitory, no significant risk premium will be required and no significant changes in stock prices will result. The rate of information arrival provides one explanation for the variation in stock prices. Lamourex and Lastrapes (1990), using trading volume as a proxy for information arrival, found that it had significant explanatory power regarding the variance of stock returns. When they included volume as an explanatory variable in the GARCH model, they found that the GARCH effect disappeared or weakened significantly. Other explanations for the variation in stock returns include the business cycle and financial crisis. Schwert (1989) found that stock volatility was higher on average during recessions and reacts strongly to banking crises. He analyzed stock volatility using the volatility of real and nominal macroeconomic variables, economic activity, financial leverage and stock trading activity covering the period of the great depression when volatility was high. He found that aggregate leverage is significantly correlated with volatility, but provides explanation for little of the changes in stock return variability. There is, however a consensus that the arrival of information provides significant explanation for the presence of ARCH in stock returns. In fact, early research by French and Roll (1986), showed that stock prices vary more during trading hours and that the availability of private information is the main reason for this.

All of the studies cited above examined developed stock markets of the United States. Leon (1996) applied GARCH formulations to returns on the Jamaica Stock Exchange (JSE), and found that stock returns are autocorrelated and negatively related to the Treasury Bill rate and that the time varying volatility of returns can be predicted using GARCH.

We go one step further and seek to explain why stock returns on the JSE exhibit time varying volatility. Variables which are likely to cause volatility in stock returns are unobservable and can be modeled parsimoniously using GARCH. One explanation for movements in stock returns volatility is the arrival of information. As information becomes available it is incorporated into stock prices causing them to move up and down accordingly. If GARCH fits the data well, then the introduction of information arrival into the model as an explanatory variable should cause the GARCH effect to disappear or at least fall.

The rest of the paper is organized as follows: Section II provides background information and data analysis. Section III specifies the model. Section IV discusses the empirical results, while section V contains the concluding remarks.

## Background Information and Data Description

The general characteristics of the nine stocks examined in this study is typified by the three most active companies on the JSE. They are Bank of Nova Scotia Jamaica Limited (BNS), National Commercial Bank (NCB) and Telecommunications of Jamaica Limited (TOJ). These three companies are dominant players on the JSE in terms of the fraction of total shares traded. Although this is so, the percentage of the stocks of these firms which are traded on the market is relatively small. Seventy percentage (70%) of TOJ is owned by Cable and Wireless with a further ten percent (10%) owned by large institutions which trade on the market infrequently. The pattern is the same for both BNS and NCB. Seventy percent (70%) of BNS is owned by BNS Canada and another 10% by large institutions which tend to use the strategy of buy and hold. This is evident in the fact that the listing of the top ten share holders does not show much change in ownership structure over time. NCB is more diversified in terms of stock holdings. Mutual Life is the major share holder accounting for approximately sixty percent (60%). These large institutions normally do not liquidate through the stock market, they usually arrange private transactions with only the residuals coming onto the public market.

Likewise for the other six companies examined, although most of the shares of these companies are not traded, the remaining portions constitutes a significant amount of the total activity on the stock market. Since the controlling ownership of these companies cannot change through normal daily activity on the JSE, it is possible that this fact could reduce the amount of volatility observed in the shares of these companies traded.

Trading on the JSE is done sequentially since 1993, with the shares of companies trading alphabetically. BNS is traded first. Given its relative importance to the market, the trading in BNS shares on any day has a major impact on the activities of the market which are to follow on that day.

The data consists of daily stock returns and trading volume of nine of the most actively traded stocks on the JSE. The level of stock activity was based on the number of board lots recorded in 1995. The listing of the top ten companies does not change very much over time, except in their relative positions within the group of ten. Board lots as opposed to volume was used because single large transactions in shares may occur which might indicate that the stock is more active than it really is. For example, in 1995, block transactions dominated trading activity on the JSE, representing approximately 87% of total market volume. This was primarily as a result of a single transaction in the shares of TOJ, with 79% of its shares being transferred to another company. Returns are calculated using daily close to closing prices and are adjusted for bonuses, stock splits and consolidations, in order to approximate the true return more accurately. No adjustment for dividend payments is necessary since the announcement of a dividend payment is public information which affects stock prices at the same time that it becomes known. The stocks are Bank of Nova Scotia (BNS), Carib Cement, Carreras (CARR), Grace Kennedy, Jamaica Producers (JAPROD), Lascelles (LASC), Life of Jamaica (LOJ), National Commercial Bank (NCB), and Telecommunications of Jamaica (TOJ). These actively traded stocks are used in order to avoid problems arising from non-synchronous trading, such as stale prices.

Table 2.1 gives the summary statistics of returns for the companies. It shows the non-normality in the underlying distribution of these stock returns. The measurement of the concentration of the distribution of stock returns around its mean in all cases was greater then 3, indicating that the distribution is leptokurtic. The Ljung Box Q test from the ordinary least squares regressions reveal the presence of significant higher order serial correlation in the residuals for all companies, except LOJ. The Autoregressive Conditional Heteroscedasticity (ARCH) test, which is based on the regression of squared residuals on lagged squared residuals, is reported for stock returns at 6 and 9 lags in Table I. These results confirm the presence of heteroscedasticity in the disturbances. Heteroscedasticity in the stock returns is expected, since between 1989 and 1997, significant changes in stock returns occurred as growth and modifications in the operations of the stock exchange took place.

Table 2.2 provides the summary statistics for trading volume. The characteristics of these data are similar to those of returns except to the extent that for the most part, volume exhibits no time varying volatility, although there is evidence of serial correlation in at least one of the sub-sample periods for all stocks. Trading activity on a particular stock on any given trading day is in response to some new information to which investors are reacting in an attempt to maximize their returns. The data on JSE reveals that serial dependence in volume traded can extend as far back as 20 periods. This implies that the market is inefficient in processing information.

## Model Specification

As the Jamaica Stock Exchange grows, trading activity becomes more frequent. Returns become more volatile, as information which is unobservable is incorporated into stock prices. In order to model this time variant volatility in stock returns in a parsimonious way, a GARCH(1,1) formulation is used as specified below.

$$r_t|\phi_{t-1} = \alpha_o + \alpha_1 r_{t-1} + \varepsilon_t \quad (1)$$

$$\varepsilon_t| \phi_{t-1} \sim t(0, h_t, d), \quad (2)$$

$$h_t = \beta_0 + \beta_1\varepsilon^2_{t-1} + \beta_2 h_{t-1} \quad + \beta_3 V. \qquad (3)$$

Where r is defined as stock returns, $\phi$ as the information set, h as the conditional variance, d as the degree of freedom in the underlying student t distribution, and V as daily trading volume.

Equation (1), the conditional mean equation, is specified as an autoregressive process in order to capture the serial correlation in returns. The conditional variance in (3) is modeled as a GARCH(1,1) process distributed as a student's t with d degrees of freedom. Thus $h_t$ is modeled as a weighted sum of past $h_t$'s and past squared residuals. $\beta_1$ and $\beta_2$ are the GARCH coefficients. Modeling with the student's t distribution allows a better estimation of highly leptokurtic JSE returns.

The daily increment of prices is influenced by the stochastic rate at which information flows into the market. In an efficient market, the rate of information arrival influence returns to the extent that all available information will be incorporated into prices. Information arrival, which is unobservable, therefore reflects the time dependence in the generation of daily stock returns volatility. Traders act on information by varying the volume as well as the price of stocks traded. That is, the market activity of a stock will depend on what information the investor has available. Daily trading volume is therefore used in this study as a proxy for information arrival. Volume is incorporated in the variance equation to test whether it has any explanatory power. The introduction of volume in the process is based on previous research done by Lamourex and Lastrapes (1990), in which they incorporated the rate of information arrival, proxied by trading volume, as an explanation for the presence of ARCH in stock returns. If the data series does not have heteroscedasticity, the estimation will indicate that we have a constant model i.e. $\beta_1$ and $\beta_2 = 0$ and hence $h_t = \beta_0$, a constant. If the GARCH effect is indeed caused by the unobservable information arrival, then volume when introduced is expected to capture at least some of the GARCH effect, thereby reducing it.

This model is estimated using maximum likelihood under the assumption that the random disturbance term, $e_t$, follows a t distribution. Using the BHHH algorithm with numerical derivations, the following log likelihood function is maximised.

$$
\begin{aligned}
l_t(\theta) = &\ln\Gamma(0.5(d+1)) - \ln\Gamma(0.5d) - 0.5\ln(d-2) - \\
&0.5\ln h_t - 0.5(d+1)\ln(1 + d_t^2/(h_{t(d-2)})) \qquad (4)
\end{aligned}
$$

## Empirical Results

Table 2.3 reports the estimated coefficients and the associated asymptotic t-statistics of the restricted model (the model without volume as an explanatory variable). The distribution of stock returns over the sample period tend to be similar among the companies. Figure 2.1 provides a graphical view of the distributions of stock returns over the sample period. BNS and Carib Cement for example, exhibit most movement in stock returns between observations 305 and 1200, coinciding with liberalization of the Stock Exchange and its increasing development and sophistication. The estimated coefficients on the GARCH variables in the restricted model are approximately 0.41 and 0.54 for both companies. The same is true for NCB and TOJ. This explains the closeness in the estimates of the coefficients in both the restricted and unrestricted models. On the other hand, the distribution of

**FIGURE 2.1**
**THE DISTRIBUTION OF STOCK RETURNS OVER THE SAMPLE PERIOD**

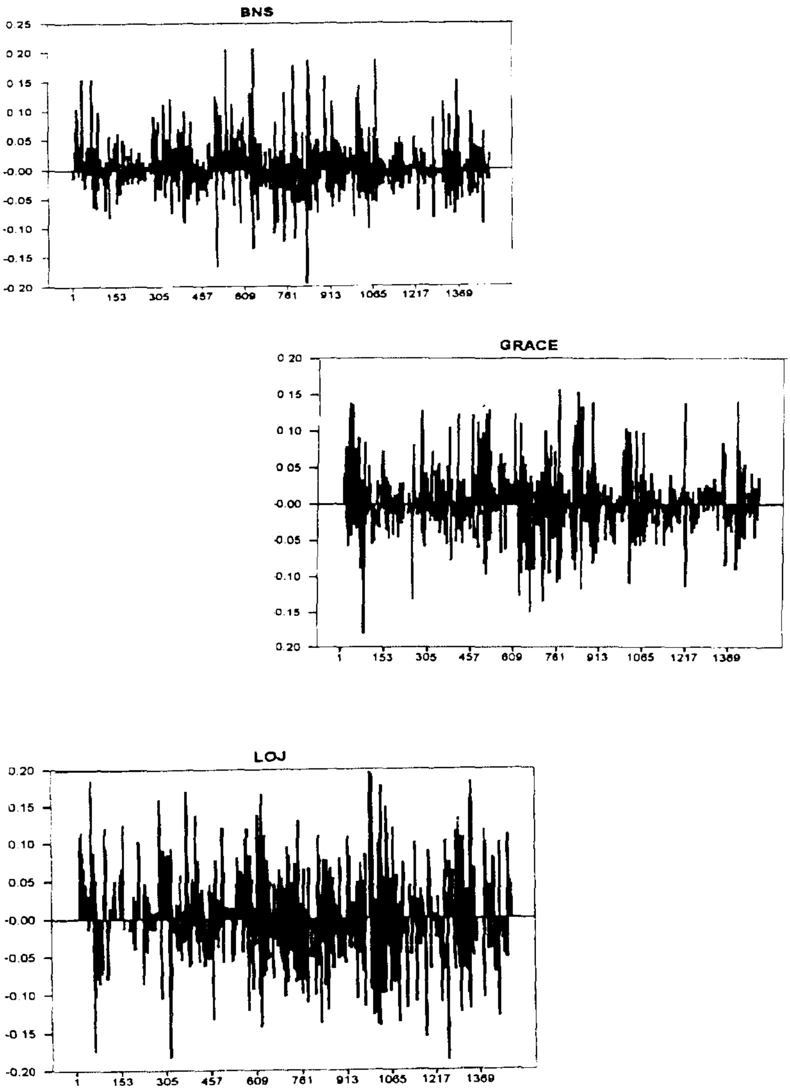
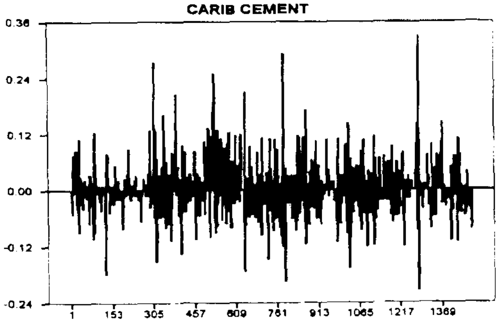
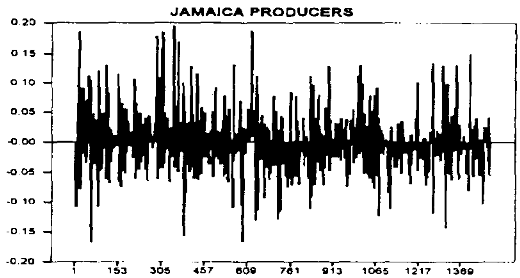


FIGURE 2.1. CONT'D
THE DISTRIBUTION OF STOCK RETURNS OVER THE SAMPLE PERIOD



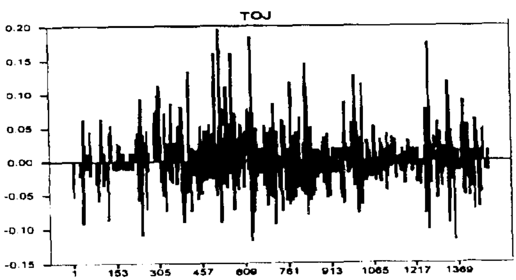
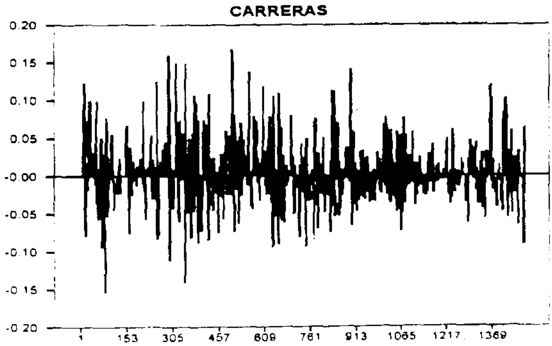
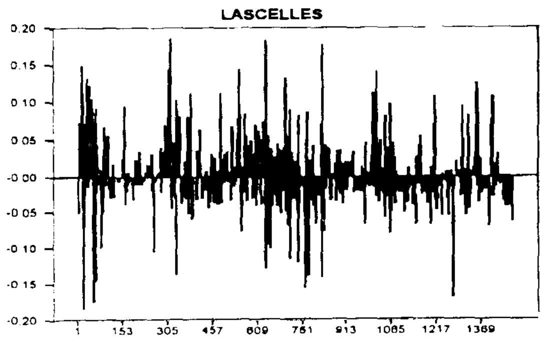
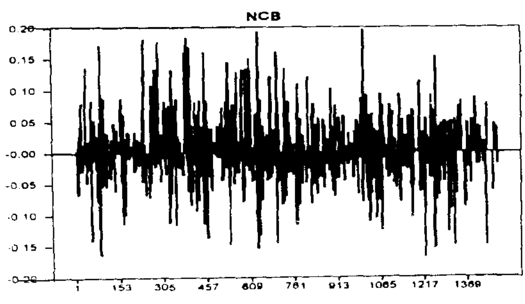



**FIGURE 2.1. CONCLUDED**
**THE DISTRIBUTION OF STOCK RETURNS OVER THE SAMPLE PERIOD**



Jamaica Producers' returns appear to be different from the other stocks examined. Likewise, the coefficients estimated in the regression equations for Jamaica Producers are noticeably different from those which emerge from regressions on the other companies. Results generated using the maximum likelihood procedure, provide no evidence that the time varying volatility in these stock returns can be characterised by the GARCH model when volume is left out of the equation. Although the ARCH test shows the presence of heteroscedasticity in the residuals, the coefficients on the GARCH variables ($\beta_1$ and $\beta_2$), appear insignificant for all stocks except Jamaica Producers. The asymptotic t-statistic on the estimated coefficients are small[1], the largest being 1.14 for Carib cement and the smallest approaching 0 in the restricted model. The t-statistics on the same company are all below 1 ranging between 0.45 and 0.97.

The results in Table 2.3 also show the presence of significant higher order serial correlation in the standardised squared residuals. The calculated Ljung Box Q-statistics ranged between 106 for NCB to 150 for BNS, implying that the GARCH process is not fully capturing the heteroscedasticity in the returns. Jamaica Producers is the only stock which has no significant serial correlation in its squared residuals. All the coefficient estimates are significant with the GARCH effect summing to just under 1. GARCH appears to model Jamaica Producers' data well, capturing all the time varying volatility in the stock returns. The joint LR test for $\beta_2$ and $\beta_3$ =0 was rejected, further substantiating this conclusion. Despite the large standard errors reported for the other eight stocks, except for NCB, the joint LR test of $\beta_1$ and $\beta_2$ = 0 suggest the presence of GARCH effects in the data. The Ljung Box Q test does not allow the rejection of the presence of higher order serial correlation in the standardised residuals, indicating that the AR(1) model used in the mean equation may not be adequately specified, since not all of the serial correlation in the stock returns are accounted for. In addition, most stocks exhibited significant divergence in the kurtosis of the standardized residuals and the implied kurtosis calculated from the degrees of freedom for the t distribution, (not reported), further supporting the point that the GARCH formulation does not fit the data well.[2]

The results of the unrestricted model are reported in Table 2.4. When volume was introduced as an explanatory variable into the model, the coefficients on the GARCH variables were not always reduced as is expected if volume provides any explanation for the heteroscedasticity in the stock returns. BNS increased marginally from 0.944 to 0.945, Grace went from 0.942 to 1.332 and Carib Cement remained constant at approximately 1.00. Other stocks such as Lascelles and TOJ fell significantly from 1 to 0.777 and 0.947 to 0.559 respectively. This occurred despite the fact that the coefficient on volume for both of these companies approached zero with large standard errors, thereby contributing nothing to the explanatory power of the model. The likelihood ratio test for $\beta_3=0$ is significant for most companies, suggesting that volume does have some explanatory power and that GARCH(1,1) is present in these returns. The standard errors generated from the regressions however, suggest the opposite. The associated asymptotic t-statistics on the estimated coefficients are all less than 2. For instance, the t-statistics on the GARCH coefficients and that of volume for BNS are 0.004, 0.350, and 0.064 respectively. This is suggesting that the model provides no significant explanations for the presence of heteroscedasticity in the stock returns. The coefficient on volume traded tended to zero for most stocks and provided no explanatory power in any of the cases. The estimated coefficient on volume traded for Carib Cement is relatively large at 0.2, but like the other stocks, its standard error is quite large, resulting in a t-statistic of only 0.74. One implication of these results is that there are factors which may not include trading volume that is influencing the time varying volatility in the stock returns.

The presence of higher order serial correlation in the standardized squared residuals further substantiate the poor fit of the unrestricted model to the data. These results seem inconsistent with the predictions which would follow from Lamourex and Lastrapes (1990), that the inclusion of volume in the model explain some of the GARCH effect that is present in the data. Based on the standard errors, the results generated from the restricted model, using JSE data, however, did not exhibit any statistically significant GARCH effect. Including volume as an explanatory variable would therefore not be expected to capture any GARCH effect, since it was statistically unimportant to begin with. Alternatively, volume may not be a good proxy for information arrival, and hence, even if GARCH fits the data well, none of the GARCH effect would be captured by volume. One reason for this is that there may be increased volume traded which has nothing to do with information flows. Lamourex and Lastrapes, (1990), found that some companies for which dividends are paid out exhibit increased trading activity around the execution date. It is the taxation of dividends which induces trading and not the arrival of information. If, on the other hand, volume is a good proxy for information arrival, then its insignificance as an explanatory variable would imply that the market is inefficient. If markets are efficient, all information which becomes available is incorporated into prices and are translated into movements in returns.

## CONCLUSIONS

Asset returns on the JSE failed to be individually modeled using the GARCH(1,1) process, despite evidence in the data of significant heteroscedasticity and higher order serial correlation in the stock returns. The persistence in volatility measured by the size of the GARCH coefficients is usually smaller than when traded volume is restricted to zero. The data, however, fails to support the hypothesis that trading volume provides an explanation for the presence of time varying volatility in stock returns. This is not the same as concluding that the rate of information arrival has no influence on heteroscedasticity in the stock returns. It merely informs that activity on the stock market is not necessarily a reflection of the arrival of new information. In other words, volume may not be a good proxy of the rate of information arrival. An alternative possibility is that the JSE is inefficient because information is not incorporated in stock prices once it becomes available.

Further work is necessary to determine whether it is just that volume traded is not a good proxy of information arrival, or that the stock market is inefficient. Additional exploration of the relationship of returns volatility with other variables is necessary to test whether the predictive content of the model can be improved.

## Notes

1. Reference to coefficient estimates exclude the constant and 1/d terms.

2. Preliminary experimentation with GARCH of different orders did not improve the results.

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## TABLE 2.1
## Descriptive Statistics for Stock Returns

**Full Period**

| | BNS | CARIB | CARR | GRACE | JPROD | LASC | LOJ | NCB | TOJ |
|---|---|---|---|---|---|---|---|---|---|
| Observations | 1520 | 1520 | 1521 | 1521 | 1523 | 1500 | 1525 | 1517 | 1525 |
| Mean | 0.0036* | 0.002 | 0.0013 | 0.0027* | 0.0021* | 0.0023* | 0.039 | 0.004 | 0.0068 |
| Variance | 0.0037 | 0.0018 | 0.173 | 0.0025 | 0.0018 | 0.0014 | 1.67 | 0.010 | 0.033 |
| Skewness | 11.03* | 1.19* | 38.44* | 7.90* | 1.511* | 2.763* | 37.87* | 18.83* | 37.001* |
| Kurtosis | 270.99* | 9.47* | 1492.4* | 198.19* | 12.59* | 35.16* | 1459.2* | 547.94* | 1418.66* |
| Q(20) | 74.76* | 80.77* | 5.19* | 39.66* | 191.28* | 71.92* | 0.644 | 188.78* | 0.116 |
| $Q^2(20)$ | 45.78* | 180.81* | 0.025 | 50.56* | 140.77* | 48.08* | 0.013 | 67.58* | 2.31-05 |
| Arch(6) | 46.24* | 140.69* | 0.015 | 48.08* | 97.88* | 31.92* | 0.003 | 64.48* | 56.13* |
| Arch(9) | 46.16* | 143.89* | 0.017 | 48.01* | 100.20* | 38.65* | 0.005 | 64.58* | 56.28* |

**TABLE 2.1. (Continued)**
**Sub-period I (03/01/89 -19/08/93 )**

| | BNS | CARIB | CARR | GRACE | JPROD | LASC | LOJ | NCB | TOJ |
|---|---|---|---|---|---|---|---|---|---|
| Observations | 760 | 760 | 760 | 760 | 760 | 760 | 760 | 760 | 760 |
| Mean | 0.005* | 0.003* | 0.005* | 0.005* | 0.004* | 0.005* | 0.071 | 0.009 | 0.004 |
| Variance | 0.006 | 0.002 | 0.001 | 0.004 | 0.002 | 0.002 | 3.28 | 0.018 | 0.001 |
| Skewness | 9.66* | 1.38* | 0.994* | 7.88* | 1.21* | 3.09* | 27.50* | 15.41* | 2.544 |
| Kurtosis | 182.02* | 8.24* | 14.42* | 160.52* | 11.00* | 37.96* | 757.71* | 332.04* | 20.42 |
| Q(20) | 66.41* | 89.09* | 51.26* | 24.84 | 151.16* | 32.42* | 0.371 | 121.38* | 75.02* |
| $Q^2(20)$ | 22.58 | 141.77* | 120.02* | 24.27 | 94.32* | 18.98 | 0.027 | 33.31* | 11.78 |
| Arch(6) | 22.67* | 105.95* | 98.72* | 22.98* | 62.39* | 12.14 | 0.007 | 31.69* | 5.71 |
| Arch(9) | 22.60* | 106.22* | 99.19* | 22.91* | 63.94* | 16.52 | 0.011 | 31.69* | 6.39 |

**TABLE 2. 1. (Concluded)**
**Sub-period 2 ( 23/08/93 -17/06/97 )**

| | BNS | CARIB | CARR | GRACE | JPROD | LASC | LOJ | NCB | TOJ |
|---|---|---|---|---|---|---|---|---|---|
| Observations | 760 | 760 | 760 | 761 | 763 | 751 | 762 | 760 | 763 |
| Mean | 0.002 | 0.001 | 0.021 | 0.001 | 0.0002 | -0.0008 | -0.002 | -0.0009 | 0.001 |
| Variance | 0.001 | 0.002 | 0.345 | 0.01 | 0.001 | 0.0011 | 0.004 | 0.002 | 0.06 |
| Skewness | 1.28* | 0.959* | 27.33* | 1.26* | 1.97* | 1.66 | -3.75 | -0.035 | 26.93* |
| Kurtosis | 8.80* | 1099* | 751.65* | 19.21* | 13.07* | 16.79* | 82.36* | 11.87* | 737.23* |
| Q(20) | 86.79* | 30.04 | 2.72 | 66.16* | 57.78* | 98.92* | 32.82* | 24.97 | 0.027 |
| $Q^2(20)$ | 98.23* | 66.95* | 0.030 | 124.16* | 24.72 | 113.48* | 2.54 | 90.30* | 2.62-0.5 |
| Arch(6) | 40.12* | 47.87* | 0.009 | 141.53* | 15.95* | 64.88* | 1.13 | 81.11* | 64.99* |
| Arch(9) | 57.55* | 51.36* | 0.014 | 141.61* | 17.01* | 76.99* | 1.17 | 84.18* | 65.08* |

**TABLE 2.2**
**Descriptive Statistics for Stock Volume**

**Full Period**

| | BNS | CARIB | CARR | GRACE | JPROD | LASC | LOJ | NCB | TOJ |
|---|---|---|---|---|---|---|---|---|---|
| Observations | 1520 | 1520 | 1521 | 1521 | 1523 | 1500 | 1525 | 1523 | 1525 |
| Mean | 79744* | 224655* | 31287* | 54755* | 65129* | 168337* | 76886* | 173320* | 2288017 |
| Variance | 9.99 | 2.2E+12 | 6.7E+09 | 3.2E+10 | 2.1E+10 | 2.8E+10 | 2.6E+11 | 1.1E+12 | 6.1E+15 |
| Skewness | 21.26* | 20.30* | 15.20* | 12.93* | 9.09* | 10.86* | 32.06* | 26.85* | 39.04* |
| Kurtosis | 538.53* | 495.97* | 354.32* | 226.67* | 133.93* | 161.33* | 1127.1* | 844.63* | 1524.4* |
| Q(20) | 40.42* | 58.43* | 44.80* | 75.90* | 247.89* | 165.57* | 5.44 | 172.66* | 0.017 |
| Arch(6) | 0.0132 | 2.58 | 0.024 | 9.17 | 0.129 | 3.54 | 0.006 | 0.011 | 0.004 |
| Arch(9) | 0.0291 | 2.59 | 0.036 | 9.33 | 5.22 | 10.27 | 0.009 | 0.018 | 0.006 |

**TABLE 2.2. (Continued)**
**Sub-period I (03/01/89-19/08/93)**

| | BNS | CARIB | CARR | GRACE | JPROD | LASC | LOJ | NCB | TOJ |
|---|---|---|---|---|---|---|---|---|---|
| Observations | 760 | 760 | 760 | 760 | 760 | 750 | 760 | 757 | 762 |
| Mean | 41935* | 134280* | 21802* | 55525* | 59063* | 47871* | 82770* | 98989* | 241812* |
| Variance | 4.9E+09 | 2.5E+11 | 1.3E+09 | 2.9E+10 | 6.7E+09 | 3.4E+10 | 5.1E+11 | 3.2E+10 | 7.7E+11 |
| Skewness | 3.82* | 20.34* | 3.87* | 11.03* | 2.84* | 12.67* | 23.81* | 5.22* | 10.81* |
| Kurtosis | 18.39* | 493.61* | 21.19* | 142.06* | 11.13* | 195.72* | 601.77* | 49.36* | 129.35* |
| Q(20) | 754.43* | 3.52* | 165.39* | 46.93* | 740.34* | 151.47* | 0.890 | 1398.1* | 60.08* |
| Arch(6) | 31.75* | 0.019 | 4.89 | 0.15 | 47.91* | 2.42 | 0.011 | 22.01* | 8.58 |
| Arch(9) | 44.74* | 0.029 | 9.04 | 0.26 | 52.55* | 6.31 | 0.018 | 22.41* | 8.62 |

**TABLE 2.2. (Concluded)**
**Sub-period 2 (23/08/93-17/06/97)**

| | BNS | CARIB | CARR | GRACE | JPROD | LASC | LOJ | NCB | TOJ |
|---|---|---|---|---|---|---|---|---|---|
| Observations | 760 | 760 | 760 | 761 | 763 | 751 | 762 | 760 | 763 |
| Mean | 117553* | 315029* | 40801* | 53985* | 71185* | 46587* | 71250* | 248140* | 4331540 |
| Variance | 1.9E+11 | 4.1E+12 | 1.2E+10 | 3.5E+10 | 3.6E+10 | 2.3E+10 | 1.8E+10 | 2.1E+12 | 1.2E+16 |
| Skewness | 15.7* | 15.35* | 13.00* | 14.33* | 8.02* | 7.09* | 4043* | 19.40* | 27.62* |
| Kurtosis | 285.69* | 276.27* | 219.94* | 14.33* | 94.47* | 64.67* | 25.07* | 434.66* | 762.82* |
| Q(20) | 6.20 | 30.02 | 9.29 | 69.11* | 72.61* | 57.50* | 641.28* | 84.94* | 0.033 |
| Arch(6) | 0.04 | 1.20 | 0.037 | 8.74 | 0.210 | 0.315 | 91.94* | 0.023 | 0.008 |
| Arch(9) | 0.06 | 1.23 | 0.062 | 8.90 | 2.42 | 1.84 | 95.11* | 0.036 | 0.012 |

## Table 2.3
## Maximum Likelihood Estimate of the GARCH(1,1) Restricted Model

Model: $r_t|\phi_{t-1} = \alpha_0 + \alpha_1 r_{t-1} + \alpha_2 h_t^{1/2} + \varepsilon_t$

$$h_t = \beta_0 + \beta_1 \varepsilon^2_{t-1} + \beta_2 h_{t-1}$$

| | BNS | | CARIB CEMENT | | CARRERAS | |
|---|---|---|---|---|---|---|
| **Coefficient** | **Estimate** | **Asymptotic T -Stat** | **Estimate** | **Asymptotic T-Stat** | **Estimate** | **Asymptotic T-Stat** |
| $\alpha_0$ | 3.13 | 0.612 | 2.99 | 1.14 | 3.13 | 0.436 |
| $\alpha_1$ | 3.69 | 0.675 | 3.64 | 0.95 | 3.70 | 0.594 |
| $\beta_0$ | 0.087 | 0.005 | 0.00009 | 0 | 0.09 | 0.004 |
| $\beta_1$ | 0.408 | 0.642 | 0.465 | 0.97 | 0.406 | 0.47 |
| $\beta_2$ | 0.536 | 0.355 | 0.535 | 0.458 | 0.536 | 0.328 |
| 1/d | 0.213* | 56.27 | 0.211 | 0.659 | 0.208* | 33.80 |
| Q(20) | 128.84* | | 161.849* | | 107.40* | |
| $Q^2(20)$ | 125.13* | | 150.63* | | 106.28* | |

**Table 2.3. (Continued)**
**Maximum Liklihood Estimate of the GARCH (1,1) Restricted Model**

| | GRACE | | JAMAICA PRODUCERS | | LASCELLES | |
|---|---|---|---|---|---|---|
| Coefficient | Estimate | Asymptotic T -Stat | Estimate | Asymptotic T-Stat | Estimate | Asymptotic T-Stat |
| $\alpha_0$ | 3.13 | 0.503 | -0.007* | -25.25 | 3.005 | 0.555 |
| $\alpha_1$ | 3.70 | 0.654 | 1.397* | 115.59 | 3.67 | 0.667 |
| $\beta_0$ | 0.091 | 0.004 | 0.00001* | 4.57 | 0.000009 | 0 |
| $\beta_1$ | 0.406 | 0.543 | 0.491* | 26.6 | 0.461 | 0.516 |
| $\beta_2$ | 0.536 | 0.349 | 0.508* | 65.768 | 0.539 | 0.328 |
| 1/d | 0.209* | 41.27 | 0.038* | 14.17 | 0.207 | 0.548 |
| Q(20) | 120.63* | | 96.54* | | 127.47* | |
| $Q^2(20)$ | 117.91* | | 8.38 | | 124.79* | |

**Table 2.3. (Concluded)**
**Maximum Liklihood Estimate of the GARCH (1,1) Restricted Model**

| Coefficient | LOJ Estimate | LOJ Asymptotic T -Stat | NCB Estimate | NCB Asymptotic T-Stat | TOJ Estimate | TOJ Asymptotic T-Stat |
|---|---|---|---|---|---|---|
| $\alpha_0$ | 3.13 | 0.612 | 1.37* | 2.33 | 3.13 | 0.461 |
| $\alpha_1$ | 3.69 | 0.675 | 3.53* | 1.97 | 3.70 | 0.602 |
| $\beta_0$ | 0.096 | 0.005 | 0.180 | 0.08 | 0.08 | 0.003 |
| $\beta_1$ | 0.410 | 0.642 | 0.457 | 0.196 | 0.411 | 0.50 |
| $\beta_2$ | 0.536 | 0.355 | 0.542 | 0.543 | 0.536 | 0.317 |
| 1/d | 0.213* | 56.27 | 0.207* | 5.015 | 0.212* | 45.65 |
| Q(20) | 128.84* | 161.84 | 107.4* | | 134.47* | |
| $Q^2(20)$ | 125.13* | 150.63 | 106.27* | | 131.99* | |

** significantly different from zero at the 5% level*

*Q(20) is the Jung Box Q test of higher order serial correlation in the standardized residuals at 20 lags.*

*$Q^2(20)$ is the Jung Box Q test for higher order serial correlation in the standardized squared residuals at 20 lags.*

*The implied Kurtosis is 1/d*

**Table 2.4**

**Maximum Likelihood Estimates of the GARCH(1,1) Unrestricted Model**

Model : $r_t|\phi_{t-1} = \alpha_0 + \alpha_1 r_{t-1} + \alpha_2 h_t^{1/2} + \varepsilon_t$

$$h_t = \beta_0 + \beta_1\varepsilon^2_{t-1} + \beta_2 h_{t-1} + \beta_3 v_t$$

| | BNS | | CARIB CEMENT | | CARRERAS | |
|---|---|---|---|---|---|---|
| **Coefficient** | **Estimate** | **Asymptotic T -Stat** | **Estimate** | **Asymptotic T-Stat** | **Estimate** | **Asymptotic T-Stat** |
| $\alpha_0$ | 3.13 | 0.611 | 2.88 | 1.20 | -1.09 | -0.061 |
| $\alpha_1$ | 3.69 | 0.673 | 3.519 | 0.94 | 3.61 | 0.322 |
| $\beta_0$ | 0.087 | 0.004 | 0.0000099 | 0 | 3.40 | 0.0065 |
| $\beta_1$ | 0.409 | 0.064 | 0.461 | 0.994 | 0.00001 | 0.00001 |
| $\beta_2$ | 0.536 | 0.350 | 0.539 | 0.510 | 0.201 | 0.0017 |
| $\beta_3$ | 0.193 | 0.004 | 0.212 | 0.736 | 0 | 0 |
| 1/d | 0.211* | 55.97 | 0.135 | 0.138 | 0.300 | 0.0443 |
| Q(20) | 127.996* | | 155.850* | | 28.61 | |
| $Q^2(20)$ | 124.39* | | 147.175* | | 27.32* | |
| LR TEST ($\beta_3$ =0 | 49.14* | | 421.524* | | 2921.2* | |
| LR TEST ($\beta_1 = \beta_2 = 0$) | 6036.5* | | 843.248* | | | |

**Table 2.4. (Continued)**
**Maximum Likelihood Estimates of the GARCH(1,1) Unrestricted Model**

| | GRACE | | JAMAICA PRODUCERS | | LASC | |
|---|---|---|---|---|---|---|
| Coefficient | Estimate | Asymptotic T -Stat | Estimate | Asymptotic T-Stat | Estimate | Asymptotic T-Stat |
| $\alpha_0$ | -0.003 | -0.6472 | 0.0162* | 16.94 | -0.007* | -29.52 |
| $\alpha_1$ | 0.947*- | 9.38 | 0.545* | 27.02 | 1.01* | 70.665 |
| $\beta_0$ | 0.0004 | 1.19 | 0.00001 | 1.41 | 0.0001* | 7.35 |
| $\beta_1$ | 0.401 | 1.19 | 0.0005 | 0.24 | 0.045* | 13.157 |
| $\beta_2$ | 0.931* | 17.45 | 0.777 | 74.69 | .0745* | 53.32 |
| $\beta_3$ | 0 | 0 | 0 | 0.508 | 0 | 0 |
| 1/d | 0.033 | 0.321 | 0.654* | 8.93 | 0.0938* | 2336801 |
| Q(20) | 223.365* | | 98.275* | | 191.854* | |
| $Q^2(20)$ | 171.93* | | 220.617* | | 16.956* | |
| LR TEST ($\beta_3$ =0) | 12604.28* | | 9708.9* | | 2917.04* | |
| LR TEST ($\beta_1$ =$\beta_2$ = 0) | 15365.02* | | 23334.9* | | 15963.86* | |

**Table 2.4. (Concluded)**
**Maximum Likelihood Estimates of the GARCH(1,1) Unrestricted Model**

| Coefficient | LOJ Estimate | LOJ Asymptotic T -Stat | NCB Estimate | NCB Asymptotic T-Stat | TOJ Estimate | TOJ Asymptotic T-Stat |
|---|---|---|---|---|---|---|
| $\alpha_0$ | 0.807* | 2.10 | 0.024* | 19.89 | -0.822 | -0.113 |
| $\alpha_1$ | 3.34 | 1.79 | 1.58* | 50.77 | 3.67 | 0.265 |
| $\beta_0$ | 0.357 | 0.005 | 0.00003 | 1.93 | 1.662 | 0.051 |
| $\beta_1$ | 0.0003 | 0.0007 | 0.00001 | 0.012 | 0.00001 | 0.00001 |
| $\beta_2$ | 0.554 | 0.007 | 0.557* | 30.78 | 0.559 | 0.181 |
| $\beta_3$ | 0 | 0 | 0 | 1.48 | 0 | 0 |
| 1/d | 0.300* | 383.19 | 0.322* | 9.27 | 0.030 | 0.064 |
| Q(20) | 48.941* | | 218.95* | | 31.78* | |
| $Q^2(20)$ | 35.288* | | 234.59* | | 32.50* | |
| LR TEST$\beta_3$ =0) | 4479.98* | | 8923.7* | | 3181.18* | |
| LR TEST($\beta_1$ =$\beta_2$ =0) | 911.54* | | -7507.27 | | 11255.08* | |

** significantly different from zero at the 5% level.*

***Q(20) is the Jung Box Q test of higher order serial correlation in the standardized residuals at 20 lags.***

***$Q^2$(20) is the Jung Box Q test for higher order serial correlation in the standardized squared residuals at 20 lags.***

***The implied Kurtosis is 1/d***

**TABLE 2.5**
**Summation of GARCH Coefficients ($\beta_1 + \beta_2$) in the Restricted and Unrestricted Models**

| Stock | Restricted | Unrestricted |
|---|---|---|
| BNS | 0.944 | 0.945 |
| CARIB CEMENT | 1.0 | 1.0 |
| CARRERAS | 0.942 | 0.201 |
| GRACE | 0.942 | 1.332 |
| JAMAICA PRODUCERS | 0.999 | 0.7775 |
| LASCELLES | 1.0 | 0.1195 |
| LOJ | 0.946 | 0.5543 |
| NCB | 0.999 | 0.55701 |
| TOJ | 0.947 | 0.55901 |

# CHAPTER 3

# STOCK PRICE MOVEMENTS AND VOLATILITY SPILLOVERS UNDER FOREIGN EXCHANGE LIBERALIZATION:

## *The Case of Jamaica, Trinidad and Tobago and the United States of America*

*Sang W. Kim*
*&*
*R. Brian Langrin*

# Stock Price Movements and Volatility Spillovers Under Foreign Exchange Liberalization:

## *The Case of Jamaica, Trinidad and Tobago and the United States of America*

*Sang W. Kim*
*&*
*R. Brian Langrin*

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## Introduction

The growing interest in the international integration of stock markets has been evidenced in many recent empirical studies. Specifically, these studies have examined the transmission of stock price movements and return volatility across national stock markets. Research has shown that there was significant stock return volatility spillovers in international stock markets, especially in light of the spillover effects of the October 1987 stock market crash on the world stock markets. Based on this, researchers have concluded that the global stock markets are becoming increasingly integrated.

Until recently, much of this research has concentrated mostly on the developed markets of the U.S., Japan, and the United Kingdom. However, with the increasing importance of the small "emerging" national stock markets of the developing world, the market integration of these markets are becoming an important research issue. As Bekaert and Harvey (1995a, 1995b) point out, these markets' stock price movements have very little correlation with those of the developed markets and hence represent a possible hedging opportunity for the investors in the developed markets. However, as Bekaert (1995) documents, much of these emerging markets have investment restrictions on foreign investors and hence much of these hedging opportunities are exploited through the closed end country funds or American Depository Receipts (ADR) that are traded on the major exchanges such as the New York Stock Exchange (NYSE).

Recent research by Kim and Rogers (1995) have shown that increased market integration and volatility spillovers occur when a stock market is liberalized to allow direct investment by foreign investors. They further postulate that it is through this hedging opportunity that information regarding the developed markets that were previously unimportant are now becoming "pertinent" to the domestic market and hence represents increased market efficiency in processing information.

While the implications of market liberalization to allow direct investment by foreign investors is now clear, it remains to be seen whether general market liberalization policies of a small economy would have a similar effect on stock market integration and the volatility spillovers. To this end, Jamaica and Trinidad and Tobago (T&T), whose national stock exchanges are small but still vibrant and relatively open to direct foreign investment. They represent two interesting cases where the overall economy is in the process of liberalization and is geographically, politically, and economically close to the U.S. This paper will take one specific step in the market liberalization process, namely the foreign exchange market liberalization, and examine whether this has lead to increased stock return volatility spillovers.

The rest of the paper is organized as follows. Section II gives a brief institutional background on the market liberalization policies and a description of the stock markets of Jamaica and T&T. Section III provides a brief review of the relevant literature. Our model and the methodology is described in section IV followed by the description of the data set in section V. Empirical results are presented in section VI and section VII presents some concluding comments.

## II. Institutional Background

Both Jamaica and T&T are island nations in the Caribbean that have close economic and political ties to the U.S. due to their geographic proximity, among other things. They have very different economic bases, with Jamaica relying on its Bauxite exports and the tourism industry and T&T on its exports of light manufacturing and petroleum products. Until recently however, the economic policies and development were very similar for both countries, especially with respect to their market liberalization policies.

Together with the stock exchange in Barbados, the Jamaica and T&T stock markets represent the only active stock markets in the

Caribbean. Some of the larger firms are cross listed and investors from these three countries (and other English speaking Caribbean countries, in some cases) enjoy resident investor status. Currently, there are plans to link all three markets and other English speaking island nations of the Caribbean through an electronic network of an over-the-counter market.

After a failure of an "allocation" system of exchange rate determination which was instituted in November 1989, the Jamaican government made a renewed attempt to establish an equilibrium in the foreign exchange market by commencing a process of economic deregulation. On September 17, 1990, the Jamaican government instituted a flexible exchange rate inter-bank system. This system allowed all authorized dealers, which now included commercial banks, to set their own buying and selling rates. In the same year, residents and non-residents were allowed to hold foreign currency accounts. This was followed by the Exchange Control (Removal of Restrictions) Order on September 25, 1991, which eliminated all exchange controls in existence since 1939, such as, prohibition of outward portfolio investment, all repatriation and surrender requirements for residents earning foreign exchange, all controls on the repatriation of interest, profits, dividends, and capital by non-resident investors, prohibitions on the holding of foreign currency accounts abroad by Jamaican residents; all exchange control requirements on current and capital account transactions (excluding portfolio outflows by deposit taking institutions), and all controls on the currency used by residents and non-residents to settle international transactions. The date of removal of exchange controls, previously set for 1992, was advanced to September 1991 in order to curtail speculation.

Beginning in January 1990, the Jamaica Stock Exchange (JSE) traded four times a week, Monday through Thursday. Up to that time, JSE traded twice a week (Tuesday and Thursday, up to January 1990) and then three times a week (Tuesday through Thursday, up to October 1991). Trading begins at 10:00 am and continues in a sequential auction market, with equities traded in an alphabetical order, until all equities had come up for trading. Recently, the most active stocks, at the completion of the trading cycle, were auctioned again before the daily trading session was completed. As Jamaica operates on Eastern Standard Time (EST) without daily light savings adjustment, JSE's trading hours overlap with that of NYSE, with NYSE trading for another two to one hour beyond JSE. With the development of telecommunication systems, Jamaican investors receive real time financial news on the trading activities in New York. Thus, in absence of market inefficiency, liquidity and market depth problems, we would expect *a priori* that any volatility spillovers from the U.S. will occur within the same day, or at the very least by the next trading day, as was found by Karoly (1995) for NYSE and Toronto Stock Exchange.

The process of the foreign exchange market liberalization in T&T has been very similar to that of Jamaica except for the institution dates. With increasing marginalization of the T&T dollar (TT$), the government instituted sweeping changes in the operation of the foreign exchange market and capital controls, beginning in April 13, 1993. TT$ was allowed to float and other non-traditional traders such as cambios (or currency dealers) were allowed to purchase and sell foreign currency. Residents as well as non-residents were allowed to hold foreign currency denominated bank accounts in addition to the removal of virtually all restrictions on repatriation of funds. The only remaining restriction was that in order to acquire 30% or more of the total issued shares of a public company, a non-resident or group of non-residents had to obtain a license from the Ministry of Finance.

T&T Stock Exchange (TTSE) operates three times a week: up until February 1989, the market traded Mondays, Wednesdays, and Fridays. Since then, the trading occurs Tuesdays, Wednesdays, and Fridays. T&T local time is one hour ahead of EST with no daylight savings adjustment. So the trading hours overlap with NYSE. As of December 1995, the total market capitalization was at TT$5.68 billion, or at the prevailing rate of exchange, US$947 million. In addition, there is a small, yet vibrant cross border trading between Jamaica and T&T. In 1993, for example, Jamaican investors invested over TT$2 million in T&T stocks while the T&T investors invested over J$146,000 in Jamaican stocks.

## III. Previous Research

An early study on the major stock markets by Eun and Shim (1989) found that the stock price movements in the U.S. stock market greatly influence short-term price movements in other major stock markets, leading to their conclusion of market integration of international stock markets. Furthermore, they found that, by and large, the effects of unexpected developments from the U.S. stock market to other international stock markets were significantly larger than shocks originating in other markets that affect the U.S. market. This result was also found by Hamao, Masulis, and Ng (1990) for the U.S., Tokyo, and London stock markets. They argued that price volatility across markets could represent a "causal phenomenon."

The link between volatility in returns and economic variables was further explored in a study by King, Sentana, and Wadhwani (1994), where a dynamic asset pricing model is used to examine financial integration among international stock markets. They reject the assumptions that idiosyncratic risk is not priced and that the "price of risk" associated with each of the underlying factors is common across countries. Additionally, the "unobservable" factors were found to be much more significant in explaining volatility in stock returns across markets than "observable" factors.

Bekaert and Harvey (1995a) found that the covariance of a segmented market and a common world factor is unlikely to explain the markets' expected returns. Furthermore, whereas the rewards to risk are common in integrated stock markets, different sources of risk in segmented markets may result in dissimilar rewards. A regime-switching, one factor asset pricing model was used to provide empirical evidence which shows that regulatory policies determine the degree of integration (or segmentation) of international financial markets. Bekaert and Harvey (1995a, 1996b) also found that the regulatory policies, such as direct barriers to investment, may not be an indicator of integration. The effects of the various barriers on integration depends mostly on the type of restrictions and whether they are binding. They base this conclusion on the fact that they found the emerging markets to have varying degrees of market integration whether or not they had explicitly carried out policies of liberalization of their stock markets. Much of the degree of the integration depended on the access (direct investment or through closed-end country funds) to the market and, to some extent, the integration of the rest of the economy. It is important to note that, notwithstanding the recent liberalization of restrictions by developing countries on foreign equity ownership, Bekaert and Harvey (1995a) found no significant evidence of increased integration.

Bekaert (1995) and Bekaert and Harvey (1995a, 1995b) also studied the stock returns and return volatility of the emerging stock markets. They show that the emerging market returns were higher, more predictable (due to market inefficiency and/or liquidity or thin market problems) with higher volatility than developed markets, and correlations with developed markets are low, thus representing attractive hedging opportunities to the investors in the developed markets.

Kim and Rogers (1995) examined whether the volatility spillovers from the developed markets increased following the stock market liberalization to allow direct foreign investments in the Korean stock market, which is one of the largest emerging markets with good liquidity and is considered to be efficient. The spillovers from the U.S. and Japan did seem to increase following the market liberalization which indicated that there was informational market efficiency.

One of the more important empirical characteristics in studying global market integration and volatility spillovers is that the trading in various markets occur at different times around the globe. For example, Hamao et al. (1990) had to adjust for the fact that the during the trading hours in New York, Tokyo had already completed its trading day while London has not yet opened for trading. However, Karolyi's (1995) study of price spillovers between the US and Canada differs from Hamao et al. (1990) and Kim and Rogers (1995), in that, the trading hours in the two markets studied were perfectly synchronous. Therefore, Karolyi's (1995) study captures the typical one-day spillover effect described in the theoretical literature. Additionally, to strengthen the previous point, more definitive inferences may be made in Karolyi's (1995) study due to the similarity in market microstructure and regulations regarding equity trading and ownership in addition to the barrier-free flow of capital and information between the U.S. and Canadian stock markets. He found that the most of the spillovers would occur within one trading day and concluded that these markets were informationally efficient.

## IV. Model and the Empirical Methodology

Thus the question remains whether the liberalization of the foreign exchange market and relaxation of capital controls in an emerging market would have increased the volatility spillovers from the developed market. As it becomes easier for foreigners and residents alike to move assets abroad, the investors, both foreign and domestic, in the emerging stock market will become more sensitive to the stock price movements elsewhere in the world, especially the developed markets. For Jamaica and T&T, much of the spillovers may occur as the direct result of the domestic investors hedging the high inflation prone domestic financial assets with a more stable U.S. dollar denominated foreign assets. This will cause the emerging market to become more integrated with the world capital markets and will increase the volatility spillovers and increase the information efficiency of the market. However, if the liberalization of foreign exchange markets does not increase direct foreign investment nor the sensitivity of domestic investors to the stock price movements elsewhere in the world, then the degree of volatility spillovers would be expected to remain the same.

Another issue in studying the volatility spillovers lies in the modeling of the second moment of the stock returns. As argued by Hamao et al. (1990), Kim and Rogers (1995), and Karolyi (1995), volatility spillovers will affect both the returns and volatility and requires that the second moment of the stock returns be modeled explicitly. Difficulty lies in the fact that the volatility spillovers is an unobservable variable and hence the regressors must be generated or some suitable instrument variable be used. To this end, we use the methodology that is similar to that used by Hamao et al. (1990), Kim and Rogers (1995), and Karolyi (1995). These studies used Generalized Autoregressive Conditional Heteroscedasticity (GARCH) models developed by Engle (1982) and Bollerslev (1986) to examine the transmission mechanism of the conditional first and second moments in stock prices across international stock markets.[1] As postulated by French and Roll (1985) and Tauchen and Pitts (1983), incorporation of news will first affect the stock volatility. GARCH allows a parsimonious parameterization of the conditional second moment that will allow a modeling of the volatility spillovers from one market to another.[2]

We are also interested in the asymmetric variance effects that can be caused by leverage effects first postulated by Black (1976). As the stock price falls and returns become negative, firms engaged in debt financing find that the leverage of the firm increases, resulting in higher return volatility when the stock prices are falling than when it is rising. While various empirical methods exist to model this asymmetry in volatility, we choose the method proposed by Engle and Ng (1993). They found that inclusion of a simple indicator dummy variable in the conditional variance equation allows for an easier parameterization, and hence estimation, and performed better in Monte Carlo experiments. Thus, our asymmetric GARCH(p,q) model of volatility spillovers can be set up as follows:

$$R_{i,t}|\psi_t = a_0 + a_1 R_{i,t-1} + a_2 h_t^{1/2} + \gamma X_{i,t} + \varepsilon_{i,t}, \qquad (1)$$

$$\varepsilon_{i,t}|\psi_t \sim t_v(0, h_{i,t}), \qquad (2)$$

$$h_{i,t} = \omega_0 + \sum_{j=1}^{q} \alpha_j h_{i,t-j} + \sum_{j=1}^{p} \beta_j \varepsilon_{i,t-j}^2 + \delta X_{i,t}^2 + \varphi V_{i,t} \varepsilon_{i,t-1}^2. \qquad (3)$$

Here, we model the returns, $R_{i,t}$, and variances, $h_{i,t}$, for Jamaica and T&T conditional on $\psi_t$, the information set available at time t. It may be useful to point out that $\psi_t$ will contain the information from the U.S. market, including the price movements of time t. The conditional mean equation contains an autoregressive term designed to capture some of the serial correlation present in the data. It also contains the GARCH in mean term to capture the effect of risk, proxied by the square root of conditional variance, on the returns. Finally the mean equation includes spillover variable, $X_{i,t}$, which are the residuals from the estimation of a univariate GARCH(1,1) model to the U.S. data.[3] The conditional variance equation defined in (3) is a GARCH(p,q) model which includes squares of the spillover variables and the asymmetric volatility effect dummy variable, $V_{i,t}$, which is 0 when the return is non negative and 1 when it is negative. We make the student *t* distribution assumption and estimate (1) to (3) using maximum likelihood estimation with ν, the degrees of freedom parameter in the student *t* distribution, as one of the estimated parameters.[4]

## V. Preliminary Data Analysis

The data used in this study consists of daily stock market index returns in percent terms at closing time for the U.S., Jamaica, and T&T stock markets. To avoid any undue effects from the October 1987 U.S. stock market crash, our sample period begins on November 10, 1987 and ends on December 31, 1995. This data is also divided into exchange control (pre-lib) and non-exchange control (post-lib) subperiods. This allows an estimation of changes in volatility spillovers from the U.S. to Jamaica and T&T stock markets following the lifting of foreign exchange controls in the respective countries. Thus, for Jamaica the pre-lib subperiod ranges from November 10, 1987 to September 19, 1991 while the post-lib subperiod ranges from October 1, 1991 to December 28, 1995. For T&T, pre-lib subperiod ranges from November 11, 1987 to April 7, 1993 and post-lib subperiod ranges from April 27, 1993 to December 29, 1995. The full data for the U.S. ranges from November 10, 1987 to December 29, 1995.

For each market, we use the most comprehensive and diversified value weighted stock index. For the U.S. stock market, the Standard & Poors 500 (S&P) index is used. For the Jamaican and T&T stock markets, the Composite Index for the respective market is used, which consists of all common stocks listed on each exchange. The primary data source is the listings of the stock exchanges of the respective countries. This study uses daily returns to capture the possible spillover effects because, as most studies in this context have determined, these effects are usually short-term.

In Table 3.1 we present the descriptive statistics for the daily stock returns. If the underlying unconditional distributions of our three return series were normal, then the skewness and kurtosis measures would all be zero. The kurtosis measure for all returns series indicate that they have a distribution that has thicker tails than the normal distribution. However, whereas the S&P returns indicate significant negative skewness in all periods, this statistic is significantly positive for the JSE and T&T returns. Overall, the descriptive statistics for the returns of JSE and S&P series during the subperiods do not deviate much from those in the full sample. However, for T&T returns, there is a dramatic reduction of kurtosis and an increase of skewness in the post-lib subperiod. It seems that the full sample results are mainly driven by these subperiod phenomena.

Engle's (1982) Autoregressive Conditional Heteroscedasticity (ARCH) Test checks for the presence of conditional heteroscedasticity and is also useful in checking for the appropriateness of applying the GARCH methodology. The test results reject the null hypothesis of homoscedasticity, for all three series in the full sample, for 4 and 8 lags at the 1% level of significance, indicating the presence of heteroscedasticity. However, ARCH effect is not present in the post-lib S&P returns. In the November 10, 1991 to March 31, 1992 subperiod (and throughout 1992), the U.S. stock prices traded within a narrow range without any major fluctuations as a reaction to sharply lowered interest rates in 1991. In fact, during 1992 U.S. stock prices were relatively flat, with the narrowest margins between highs and lows in history. This phenomenon may explain the low ARCH test statistic for the post-lib subperiod.

Several studies (*e.g.*, Scholes and Williams, 1977) have shown that institutional factors such as non-synchronous trading and bid-ask spreads may induce serial correlation in stock returns. The Breusch-Godfrey LM test verifies, at the 1% significance level, that there exists first-order autocorrelation in all subperiods of JSE and T&T returns, while finding only marginal presence of first-order autocorrelation (or none, in the pre-lib subperiod) for the S&P returns. Moreover, the Ljung-Box (LB) Q statistics for 10 lags reject the null hypothesis of no autocorrelation for JSE and T&T returns for all subperiods, confirming the presence of serial correlation.[5] The serial correlation is either absent or much weaker in the case of the U.S. stock market. This significant difference in the results may be seen as overwhelming evidence that the characteristic non-synchronous and infrequent trading of securities in the JSE and T&T induces significant serial correlation in the series for all subperiods.

The contemporaneous and lagged cross-correlations of close-to-close returns and squared returns for the three return series are presented in Table 3.2. The cross-correlations between the returns and squared returns are all fairly low, unlike those between developed stock markets reported by Hamao et al. (1990) and others. This observation is in line with that found by Kim and Rogers (1995) and Bekaert and Harvey (1995a) of emerging, less developed market returns' low correlation with the returns of developed markets. Even between the two regional stock markets of Jamaica and T&T, the cross-correlations are very low, ranging between 0.005 and 0.108 in absolute value.

However, there is a striking increase in the contemporaneous cross-correlation between S&P and JSE following the foreign exchange market liberalization. This increase is observed both for return levels and the squared returns. Between S&P and T&T, however, the increase in cross-correlations between the two subperiods are not as large in the levels and negligible in the squares. Also, the cross-correlation on JSE mean returns lasts until day two and then tapers off, while at the same time, the cross-market influence on squared returns is interchangeably weaker and stronger as the lag length increases.

According to Eun and Shim (1989), we may infer from the correlation coefficients the degree of financial integration between two countries. However, Berkaert and Harvey (1995a) suggest that this correlation may not reflect financial integration but rather a different country-specific industry mix. Notwithstanding this, the contemporaneous and lagged correlations provides some very interesting results. The findings of other researchers in the literature are that spillover effects are short-term (usually one day) and then taper off rapidly. However, the data in this study suggest that this phenomenon occurs only in the latter subperiod when all foreign exchange restrictions that existed previously had been lifted.

## VI. Estimation Results

Our empirical strategy is to estimate a GARCH(1,1) model described in (1) to (3), without the $X_{k,t}$ variables, for S&P returns. Using the squared residuals from this estimated model, we generate the spillover variables $X_{k,t}$. We "match" up the spillover variables so that the most recent spillover variable is used. This is important because the JSE and TTSE trade only four and three times a week, respectively, while the NYSE trades five times a week. Also, the non-synchronous exchange holidays make this critical in aligning the spillover effects properly.

We report the estimation results of the basic GARCH model for JSE and T&T in Table 3.3, along with some diagnostic statistics.[6] As can be seen, we found GARCH(2,2) to provide the best fit for JSE returns while GARCH(1,1) provided the best fit for T&T and S&P returns. All variations of GARCH specifications, up to GARCH(3,3), were estimated for JSE and T&T returns. We then chose the most parsimonious GARCH specification given that it provided a similar fit as the more complex one.

For both JSE and T&T returns, our estimation seems to fit the data well, judging by the similarity in the kurtosis of the standardized residuals and the implied kurtosis calculated from our estimated degrees of freedom term for the student *t* distribution. Also, the absence of higher order serial correlations in the squared residuals implies that the GARCH model was able to model the heteroscedasticity, but the high Q statistics for the residuals indicate that our AR(1) specification for the mean equation is unable to account for the persistence of the returns. However, since our main interest is in the modeling of the second moment, for the sake of parsimony, we will not include any additional AR parameters. The GARCH in mean term, $a_2$, is positive as expected given the risk-return tradeoff.

Interestingly, our asymmetric variance term, $\varphi$ is significant and negative, implying the "reverse" leverage effect. It was hypothesized by the leverage argument that the higher leveraged firms will find that their leverage ratio will increase with falling stock prices and thus the volatility will respond more to falling prices (bad news) than rising prices (good news). One possible explanation for this unexpected outcome is that these markets, in order to survive, have had to establish some rein on excess volatility, putting some limits to the volatility movements. Also, because these two markets are quite thin by any international standards, the volatility will not immediately be able to respond fully to most new information, resulting in some dampening effect on excess volatility.

## SPILLOVERS FROM THE U.S. MARKET

We now use the squared residuals from the GARCH estimation of S&P returns to form spillover variables, $X_t$. Using these variables, we will be able to determine if there are any spillover effects from the U.S. to these two markets and if these effects have increased with the foreign exchange market liberalization. If the fixed exchange rate regime and the capital controls were binding barriers to entry, then we would expect to see an increase in the volatility spillovers in the post-lib subperiod. Thus, our GARCH model for the JSE and T&T stock returns with volatility spillovers can be set up as follows:

$$R_{i,t}|\psi_t = a_0 + a_1 R_{i,t-1} + a_2 h_t^{1/2} + \gamma_1 X_{i,t} + \gamma_2 D_{i,t} X_{i,t} + \varepsilon_{i,t}, \tag{4}$$

$$\varepsilon_{i,t}|\psi_t \sim t_v(0, h_{i,t}), \tag{5}$$

$$h_{it} = \omega_0 + \sum_{j=1}^{q} \alpha_j h_{i,t-j} + \sum_{j=1}^{p} \beta_j \varepsilon_{i,t-j}^2 + \delta_1 X_{i,t}^2 + \delta_2 D_{i,t} X_{i,t}^2 + \varphi V_{i,t} \varepsilon_{i,t-1}^2. \tag{6}$$

Here, $D_{i,t}$ are the dummy variables that equals 1 in the post-lib subperiod for the JSE and T&T and 0 otherwise. Thus, $\gamma_2$ and $\delta_2$ terms describe the increase (if positive) or decrease (if negative) in the volatility spillovers from the U.S. to these markets in the mean returns and volatility, respectively. Other parameters and variables are as described for equations (1), (2), and (3).

Maximum likelihood estimation results of (4) through (6) are given in Table 3.4. The most striking difference of this model with volatility spillovers is that the asymmetric volatility term, j, are zero for both JSE and T&T. It would seem that the asymmetric volatility effects are well approximated by the spillovers from the U.S. As noted before, the model fits the data well, however, it performs better at fitting the heteroscedasticity than it does the mean returns, as shown by the Q tests.

Of greater interest to us is the significance of the volatility spillovers and whether it has increased following the foreign exchange market liberalization. For JSE conditional variance equation, the spillovers have the hypothesized positive sign in that increased spillovers will cause JSE return volatility to increase as well. The magnitude increases drastically following the foreign exchange market liberalization, going from 0.001 for the full sample to 0.212 for the postlib subperiod. For the mean equation, we see that for the full sample, increased spillovers will cause the JSE returns to rise. But following the liberalization, the spillover coefficient is negative, implying that the volatility spillovers have less impact on the returns. But why the change in the sign? It may be that before liberalization, the low correlation with U.S. returns meant that none of the foreign nor domestic investors could diversify away the risk in the U.S. market (during high volatility periods) by moving funds invested in the U.S. into the JSE. But with the liberalization, such capital movements could occur and hence the negative post-lib relationship between U.S. volatility and the JSE returns. This implies an increase in the informational efficiency in the market. Using the LR test to test the null hypothesis of zero increase in spillovers in the post-lib period, the LR(2) test statistic (21.68) indicates that the null will be rejected at all reasonable significance levels.[7] LR(4) test statistic for the null of no volatility spillovers at all is also strongly rejected.

Another interesting result is that the GARCH parameters for the second lags, $\gamma_2$ and $\delta_2$, are no longer significant. In fact, LR(2) statistic testing the null of zero second lag coefficients could not be rejected, implying that the volatility persistence has been reduced with the introduction of the volatility spillover variables. Lamoreaux and Lastrapes (1990) have argued that the GARCH effect is caused by the processing of the newly arrived information by the market, this reduction in persistence of GARCH effects can be seen as our volatility spillover variable being able to proxy some of these information effects.

On the other hand, T&T returns and volatility shows that the spillovers from the U.S. is practically non-existent. The estimates of the $\gamma$ coefficient are very small and not significant, and $\delta$ coefficients are also very small and only the full sample coefficient is significant. However, the LR(4) statistic for the significance of the volatility spillovers is rejected strongly, implying that the volatility spillovers do affect the returns and return volatility of T&T. The variance equation spillovers variables both have the expected positive signs. The mean equation signs are just opposite of what was found for the JSE: the full sample coefficient is negative and post-lib coefficient is positive. LR(2) test to test the increase in the spillovers following the foreign exchange market liberalization cannot be rejected even at 10% significance level. While this may be a result of the short post-lib subperiod for T&T data, such small coefficients seem to indicate that the volatility spillovers did not increase. This can be a result of the fact that the barriers to entry for T&T was not binding even before the foreign exchange market liberalization, which allowed significant spillovers to occur, and hence liberalization should not be expected to cause an increase in the spillovers.[8] This could be an indication that while the foreign exchange market liberalization in Jamaica amounted to a removal of some binding barriers to entry while it did not in T&T.

## VII. Concluding Remarks

In this study, we were interested in finding out if the foreign exchange market liberalization with the market determined exchange rates and removal of controls on the movement of capital across the borders of Jamaica and T&T represented a removal of binding barrier(s) to entry. This barrier(s) could keep the foreign investors out, but more importantly, it would keep the domestic investors in, and the combined effect, without any alternative means (such as the closed end country fund, American Depository Receipts, etc.) would keep the domestic market relatively free from volatility spillovers from the U.S. market. Our empirical results show that while the liberalization policy in Jamaica has led to increased spillovers, it did not in T&T.

As the volatility spillovers are found to be important in explaining the volatility in both markets, it was argued that the pre-liberalization conditions were more binding in Jamaica than in T&T. Thus, with the relaxation of these barriers, spillovers would increase for Jamaica but not for T&T.

There is an alternative explanation, one that is more problematic to prove. The fact that TTSE is a smaller market than JSE may imply that market efficiency problems found in small markets such as liquidity problems, thin markets, and infrequent trading, could be worse than JSE and cause the spillovers not to occur, or more likely, prevent the full spillovers from occurring. As more work is done in the area market micro-structure, we will no doubt understand the effects of these market inefficiencies on the volatility spillovers.

Finally, there is the possibility, albeit a small one, that there still remains other barriers to entry. But if we accept the explanation that there still remains other binding barriers to entry, then more work needs to be done to identify these barriers. With respect to informational efficiency of the market, this is critical as these barriers are causing investors to not use all available information and hence cause inefficiency in the market.

## NOTES

1. GARCH models and their applications in finance are surveyed by Bollerslev, Chou, and Kroner (1993).

2. However, as King et al. (1994) points out, the sources of changes in volatility cannot be distinguished according to the source in the GARCH models.

3. This is the methodology used by Hamao et al. (1990) and Kim and Rogers (1995).

4. We use Bernt, Hall, Hall, and Hausman (BHHH) algorithm using numerical derivatives in our maximum likelihood estimation.

5. In fact, we found serial correlation at all lags, from 1 to 10, using Breusch-Godfrey test and for up to 20 lags using Ljung-Box Q test. For space considerations, we refrain from reporting those results here. Results are available from the authors.

6. We refrain from reporting the estimation results for S&P returns as this has been widely reported by other researchers. The results are available from the authors as well as other sources such as Kim and Rogers (1995) and Karolyi (1995).

7. Our spillover variables may suffer from the "generated regressor bias" described by Pagan and Ullah (1988), which could impart a bias in our LR statistics. The

complexity of the model makes correction for this problem difficult. But since our rejected LR statistics are very large and not rejected are very small, our results are still suggestive even with this problem.

8. We thank Peter-John Gordon for providing this interpretation.

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## TABLE 3.1
## Summary Statistics for S&P, JSE, and T&T Stock Returns

**Full Period:**[1]

| | JSE | S&P | T&T |
|---|---|---|---|
| Observations | 1340 | 2055 | 1216 |
| Mean | 0.1642$^{*}$ | 0.0450$^{**}$ | 0.1057 |
| Variance | 2.9994 | 0.6684 | 0.4605 |
| Skewness | 0.8060$^{*}$ | -0.6410$^{*}$ | 1.0952$^{*}$ |
| Kurtosis | 6.4660$^{*}$ | 6.6060$^{*}$ | 19.1241$^{*}$ |
| ARCH(4) | 198.3328$^{*}$ | 54.5169$^{*}$ | 339.2600$^{*}$ |
| ARCH(8) | 220.3775$^{*}$ | 92.6349$^{*}$ | 339.7081$^{*}$ |
| LM(1) | 415.1466$^{*}$ | 6.5277$^{**}$ | 315.5877$^{*}$ |
| Q(10) | 527.6461$^{*}$ | 20.3214$^{**}$ | 1013.4574$^{*}$ |

**Jamaica**[2]

| | Pre-lib Subperiod: | | Post-lib Subperiod: | |
|---|---|---|---|---|
| | JSE | S&P | JSE | S&P |
| Observations | 480 | 976 | 857 | 1072 |
| Mean | 0.2737$^{*}$ | 0.0477 | 0.0950 | 0.0429$^{**}$ |
| Variance | 1.8527 | 1.0152 | 3.6126 | 0.3569 |
| Skewness | 0.7344$^{*}$ | -0.6720$^{*}$ | 0.8600$^{*}$ | -0.2425$^{*}$ |
| Kurtosis | 6.5051$^{*}$ | 5.0501$^{*}$ | 5.7892$^{*}$ | 2.5273$^{*}$ |
| ARCH(4) | 70.0656$^{*}$ | 15.9971$^{*}$ | 130.0470$^{*}$ | 8.5102$^{***}$ |
| ARCH(8) | 73.8432$^{*}$ | 30.4732$^{*}$ | 146.3414$^{*}$ | 11.2352 |
| LM(1) | 64.3028$^{*}$ | 2.3676 | 258.4384$^{*}$ | 5.6549$^{**}$ |
| Q(10) | 301.4653$^{*}$ | 14.2231 | 308.3080$^{*}$ | 13.4743$^{**}$ |

## TABLE 3.1. (Concluded)
## Trinidad and Tobago (T&T)[3]

| | Pre-lib Subperiod: T&T | Pre-lib Subperiod: S&P | Post-lib Subperiod: T&T | Post-lib Subperiod: S&P |
|---|---|---|---|---|
| Observations | 802 | 1368 | 408 | 675 |
| Mean | 0.0443 | 0.0438 | 0.1787* | 0.0516** |
| Variance | 0.4303 | 0.8531 | 0.3441 | 0.2995 |
| Skewness | 0.2206* | -0.6476* | 1.5750* | -0.2043** |
| Kurtosis | 24.9595* | 5.5965* | 5.6694* | 1.3789* |
| ARCH(4) | 221.6948* | 26.5728* | 54.3510* | 11.3142** |
| ARCH(8) | 221.7812* | 48.6232* | 62.3123* | 13.1675 |
| LM(1) | 122.8287* | 3.3138** | 153.2054* | 6.0506** |
| Q(10) | 777.9928* | 16.1228*** | 217.5062* | 11.5077 |

[1] The full period for all three markets range from November 10, 1987 to December 29, 1995

[2] For Jamaica, the pre-lib subperiod ranges from November 10, 1987 to September 19, 1991 and the post-lib subperiod ranges from October 1, 1991 to December 28, 1995.

[3] For T&T, the pre-lib subperiod ranges from November 10, 1987 to April 7, 1993 and the post-lib subperiod ranges from April 27, 1993 to December 29, 1995.

*Significantly different from zero at 1% significance levels.

**Significantly different from zero at 5% significance levels.

*** Significantly different from zero at 10% significance levels.

**TABLE 3.2. Cross-correlations Between JSE, T&T, and S&P Returns**

**Panel A:**
**Return Levels**

| | | JSE | | T&T | |
|---|---|---|---|---|---|
| | **Lags** | **Pre-lib** | **Post-lib** | **Pre-lib** | **Post-lib** |
| | 0 | 0.0001 | 0.0636 | 0.0342 | 0.0722 |
| S&P | 1 | -0.0158 | -0.0131 | 0.0154 | 0.0471 |
| | 2 | 0.0265 | -0.0532 | 0.0229 | -0.0055 |
| | 0 | | | 0.0557 | 0.1089 |
| JSE | 1 | | | 0.0630 | 0.0713 |
| | 2 | | | -0.0056 | 0.0313 |

**Panel B:**
**Squared Returns**

| | | JSE | | T&T | |
|---|---|---|---|---|---|
| | **Lags** | **Pre-lib** | **Post-lib** | **Pre-lib** | **Post-lib** |
| | 0 | -0.0039 | -0.0278 | -0.0299 | 0.0285 |
| S&P | 1 | -0.0643 | -0.0647 | -0.0338 | -0.0140 |
| | 2 | 0.0677 | 0.0101 | -0.0256 | 0.1138 |
| | 0 | | | -0.0477 | 0.0854 |
| JSE | 1 | | | -0.0498 | 0.0146 |
| | 2 | | | -0.0156 | 0.0593 |

**TABLE 3.3. GARCH Estimation of JSE and T&T Returns Without Spillover Terms**

**Model:**

$$R_{i,t}|\psi_t = a_0 + a_1 R_{i,t-1} + a_2 h_t^{1/2} + \varepsilon_{i,t},$$

$$h_{it} = \omega_0 + \sum_{j=1}^{q} \alpha_j h_{i,t-j} + \sum_{j=1}^{p} \beta_j \varepsilon_{i,t-j}^2 + \varphi V_{i,t} \varepsilon_{i,t-1}^2 .$$

| | JSE (-2186.45)[1] | | T&T (-693.66)[1] | |
|---|---|---|---|---|
| Coefficient | Estimate | Asymtotic T-Stat. | Estimate | Asymtotic T-Stat.. |
| $a_0$ | -0.0730 | -2.7295 | -0.0131 | -1.1809 |
| $a_1$ | 0.4268 | 22.0293 | 0.4497 | 19.5017 |
| $a_2$ | 0.0690 | 1.6190 | 0.0388 | 0.7656 |
| $\omega_0$ | 0.0094 | 2.0316 | 0.0075 | 6.3238 |
| $\alpha_1$ | 0.3166 | 7.4234 | 0.6327 | 9.2301 |
| $\alpha_2$ | 0.2176 | 3.9725 | - | - |
| $\beta_1$ | 0.2331 | 1.4289 | 0.3673 | 13.1374 |
| $\beta_2$ | 0.2328 | 2.1363 | - | - |
| $\varphi$ | -0.1782 | -3.9995 | -0.1936 | -2.5425 |
| $1/\nu$ | 0.1899 | 13.3844 | 0.2418 | 17.5146 |
| Sample Kurtosis | | 7.3753 | | 46.8073 |
| Implied Kurtosis[2] | | 7.7495 | | 47.3256 |
| Q(20)[3] | | 82.5403* | | 66.3810* |
| $Q^2$(20)[4] | | 29.0045 | | 2.6003 |

1 Numbers in the parenthesis are Log-likelihood.
2 Implied kurtosis calculated from the estimated value of $\nu$.
3 Ljung-Box Q test for the presence of higher order serial correlation in the standardized residuals at 20 lags.
4 Ljung-Box Q test for the squared standardized residuals at 20 lags.
* Significantly different from zero at 1% significance levels.

## TABLE 3.4. GARCH Estimation of JSE and T&T Returns with Spillover Terms

**Model:**

$$R_{i,t}|\psi_t = a_0 + a_1 R_{i,t-1} + a_2 h_t^{1/2} + \gamma_1 X_{i,t} + \gamma_2 D_{i,t} X_{i,t} + \varepsilon_{i,t},$$

$$h_{it} = \omega_0 + \sum_{j=1}^{q} \alpha_j h_{i,t-j} + \sum_{j=1}^{p} \beta_j \varepsilon^2_{i,t-j} + \delta_1 X^2_{i,t} + \delta_2 D_{i,t} X^2_{i,t} + \varphi V_{i,t} \varepsilon^2_{i,t-1}.$$

| | JSE | (-2064.50)[1] | T&T | (-693.66)[1] |
|---|---|---|---|---|
| **Coefficient** | **Estimate** | **Asymtotic T-Stat.** | **Estimate** | **Asymtotic T- Stat.** |
| $a_0$ | -0.0727 | -1.5994 | -0.0038 | -0.2716 |
| $a_1$ | 0.4732 | 17.6482 | 0.4674 | 18.0082 |
| $a_2$ | 0.0786 | 1.5596 | 0.1667 | 0.3026 |
| $\gamma_1$ | 0.0191 | 0.7351 | -0.0007 | -0.0911 |
| $\gamma_2$ | -0.0576 | -1.0861 | 0.0063 | 0.4013 |
| $\omega_0$ | 0.0463 | 2.0787 | 0.0086 | 4.0651 |
| $\alpha_1$ | 0.4135 | 5.8626 | 0.6355 | 8.2581 |
| $\alpha_2$ | 0.0215 | 0.1226 | - | - |
| $\beta_1$ | 0.5385 | 1.3542 | 0.3645 | 11.5385 |
| $\beta_2$ | 0.0265 | 0.1122 | - | - |
| $\delta_1$ | 0.0012 | 0.1269 | 0.0047 | 2.2962 |
| $\delta_2$ | 0.2124 | 2.14256 | 0.0004 | 0.0908 |
| $\varphi$ | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| $1/\nu$ | 0.1952 | 9.0087 | 0.2408 | 15.3211 |
| Sample Kurtosis | | 7.4464 | | 41.8224 |
| Implied Kurtosis[2] | | 8.3401 | | 42.3743 |
| Q(20)[3] | | 65.2813* | | 73.6935* |
| $Q^2(20)$[4] | | 22.9796 | | 2.6003 |
| LR(2) $H_0: \gamma_2 = \delta_2 = 0$ | | 21.6780* | | 2.0501 |
| LR(4) $H_0: \gamma_1=\gamma_2=\delta_1=\delta_2=0$ | | 229.8800* | | 85.8640* |
| LR(2) $H_0: \alpha_2 = \beta_2 = 0$ | | 14.0205* | | - |

1 Numbers in the parenthesis are Log-likelihood.
2 Implied kurtosis calculated from the estimated value of $\nu$.
3 Ljung-Box Q test for the presence of higher order serial correlation in the standardized residuals at 20 lags.
4 Ljung-Box Q test for the squared standardized residuals at 20 lags.
* Significantly different from zero at 1% significance levels.

# CHAPTER 4

# FORECASTING INFLATION USING VAR ANALYSIS

*Wayne Robinson*

# FORECASTING INFLATION USING VAR ANALYSIS

*Wayne Robinson*[1]

## INTRODUCTION

Given the objective of price stability, the ability to predict the process of price adjustments is essential. From a policy perspective, an understanding of the interactions and transmission process between the main macroeconomic variables and prices serves to guide the process of policy formulation and implementation. In understanding and predicting inflation in Jamaica it is necessary to understand the importance of shocks and the underlying process. Critical elements of which are the persistent components such as expectations, indexation and the structural factors such as the openness of the economy, as well as the production function. This paper by exploring these interrelations, attempts to provide an alternate means of forecasting inflation by employing a Vector Autoregressive (VAR) model. In so doing it attempts to elucidate some aspects of the transmission process.

Previously, forecasting and policy analyses have been conducted using structural macroeconomic models; developed along the lines of the Cowles Commission approach. These structural models, using hypothesized theoretical relations, show the main linkages in the economy. These models thus rely on economic theory to determine the number of variables and their influence.

The initial relative success of this approach led to the development of large scale models, the most noted of which were the

MIT, Penn State and the Federal Reserve models. During the late seventies, however, these models were criticized by Lucas as being highly inappropriate for policy analysis as they violated the 'policy invariance' property. More recently, Sims (1980) in a seminal critique argued that the restrictions applied to structural models in the estimation procedure were 'incredible' and could not be properly tested.

Under the Cowles Commission approach, if a particular structural form or parametization that is derived from economic theory, fails to be identified by the data, the parameter space is then transformed such that each point uniquely represents distinct behavioural patterns. This as Sims (1980) notes is termed normalization. Generally such normalization involves the estimation of the reduce form of the structural model. Sims (1980) argues however that "having achieved identification in this way, the equations of the model are not products of distinct exercises in economic theory."[2] The fact is that in structural models, to achieve identification, often restrictions are imposed which have no theoretical justification. Further, and more importantly, Sims asserts that such restrictions are not necessary for the intended use of macromodels (i.e. forecasting and policy analysis).

Alternatively, he suggested that, "Instead of using reduced forms one could normalize by requiring the residuals to be orthogonal across equations and the coefficient matrix of current endogenous variables to be triangular."[3] This lead to the development of VAR modelling, which has proven to be quite useful in short term forecasting. VAR models have increasingly been used in macroeconomic research over the last decade or so, especially in the United States.[4] Currently VARs are used by the various branches of the Federal Reserve Bank and the Bank of England for forecasting economic trends.

Because many variables do affect inflation, and are in turn affected by inflation, it is possible to identify a small selection of economic variables, movements in which appear to have been highly correlated with inflation in the past and as such may then be useful in forecasting future inflation. The VAR approach provides a convenient means of accomplishing this, as it relies on the causal and feedback relation amongst variables.

The paper is organized as follows. The first section briefly overviews the more recent models of price behaviour. These will be used as benchmarks for comparison with the VAR model. Section II looks at a theoretical overview of the methodology whilst section III looks at the empirical model and its results. In this section a comparison of the forecasting performance of the VAR model with other time series models is done. The paper concludes by looking at the implication of the results in section IV.

## II. Recent Models

Various economists have attempted to empirically analyze the issues outlined in the previous section. Earlier studies, such as Bourne and Persaud (1977) and Holder and Worrell (1985), emphasized the role of structural influences and cost push inflation. More recent studies have found that monetary disequilibrium and exchange rate changes are significant in explaining the behaviour of prices in the Jamaican economy[5]. The link between the money stock and inflation occurs via a monetary transmission process whereby the amount of money economic agents desire to hold is less than the available money stock. Assuming a stable demand for money, this serves to reduce the value of money (in terms of goods) thus increasing the price level.

Ganga(1992) estimated a model similar to the Harberger model using two-stage least squares. The results using annual data were

$$\begin{aligned} \ln p &= 0.066 - 0.112\ln(ms) + 0.167 \ln(ms_{t-1}) \\ &- 0.137\ln(wg) + 0.315\ln(pm) \\ &+ 0.338\ln(xrate) - 0.378\ln(rgdp) + 0.229 \ln(P_{t-1}) \end{aligned}$$

Only the contemporaneous money stock and wage rate had unexpected signs and were insignificant. The results suggest that output fluctuations and exchange rate changes had the largest impact on price changes. These results of course are highly influenced by the unique features of the sample period. Using monthly data from 1990 to 1992 the estimated model was

$$\begin{aligned} \ln p &= 0.007 + 0.156\ln(xrate_{t-1}) + 0.285\ln(ms_{t-1}) \\ &+ 0.006INT_{t-1} + 0.554\ln(p_{t-1}) \end{aligned}$$

which suggest that inflation is highly influenced by lagged money supply and exchange rate changes.[6] These results also highlight the significant role of inflationary expectations.

Shaw(1992), starting from the hypothesis of the Quantity Theory, estimated the relationship between money supply and prices in Jamaica between 1982 and 1992. The changes in prices were examined as a function of changes in the money supply(M2), previous price changes and changes in the exchange rate. Using quarterly data, the estimated model most preferred was

$$p_t = 0.27 + 0.28\Delta ms_{t-2} + 0.38\,\Delta p_{t-1} + 0.24\,\Delta ex_t$$

From this he concludes the inflation rate is influenced by changes in the money supply, but not directly as the Quantity Theory purports. Monetary changes affect inflation indirectly because of the prevalence of mark-up pricing. This also provides the channel for the impact of exchange rate adjustments (i.e. changes in the exchange rate affect variable cost) and lagged prices.

Thomas(1994) attempts to capture the dynamics of the inflationary process and the relationship with respect to policy shocks in a monetarist framework. He employed a hybrid methodology which combined a distributed lag specification with an error-correction approach. The distributed lag - polynomial lag, was used to capture the short run impact of policy shocks.

Theoretically, he used a small country assumption in which the economy is a price taker in the international market. Thus the domestic price level, by the law of one price is given by

$$P = eP^*$$

where $P^*$ is the international price level and e is the exchange rate. Given this his model is specified as

$$P = p(e, P^*, c, f)$$

the steady state long run model is

$$P_t = 80.34 + 6.88e_t + 0.002c_t + 0.80I_t - 0.80\,P_t^* + 0.02f_t$$

the short run polynomial lag model is

$$\Delta P_t = -1.67 + 20.84\,\Sigma\Delta e_{t-i} + 0.0003\,\Sigma\Delta i_{t-i} + 1.10\,\Sigma\Delta\, P_{t-i}^* - 0.32\Sigma\Delta\, T_{t-i} + 0.001\Sigma\Delta\, f_{t-i} - 0.385\, u_{t-1}$$

Thomas concluded from these results that exchange rate changes exert the most dominant influence. This is however in contrast to the results of insignificant coefficient estimates for the short run model. The model in itself maybe subject to over paramatization. The model selection criterion used may also not have been the most appropriate in an ECM framework.

Downes, Worrell and Scantlebury-Maynard (1992) estimated an encompassing model of inflation for Jamaica, which incorporated both structuralist and monetarist features. The functional structure of their model is given as

$$P = p(er, usp, m^s, r, wr, prod, s)$$

Changes in the price level (P) are modelled as being positively related to the changes in the money stock ($m^s$), exchange rate (er), U.S. inflation (usp), lending rate (r), domestic wage rate (wr) , factors which cause domestic inflation to deviate from purchasing power parity equivalent (s) and negatively related to changes in productivity (prod).

Using annual data, the results of the static long run equation suggest that cost push variables such as the loan rate and the wage rate do not influence the inflation rate in the long run. Using the generalized instrumental variable estimator technique, the short run dynamic error correction model was

$$dlp = -0.03 + 0.22\, dler + 1.65\, dlusp + 0.39\, dlm1 - 0.15\, HURDUM - 1.03ec(-1)$$

which suggests that changes in the exchange rate, U.S. inflation and monetary changes have significant effect on the inflation rate. (HURDUM is a dummy variable for hurricane). In the short run therefore the model emphasized the role of monetary variables as against structural variables.

For the purpose of this paper a monthly version of this encompassing model (ECPM) was estimated. The long run static model in logs was found to be (the t-statistics is given in parenthesis)

$$\underset{}{lp} = \underset{(-0.2)}{-0.005} + \underset{(19.3)}{1.39lp_{t-1}} \underset{(-1.93)}{-0.238lp_{t-2}} - \underset{(-3.1)}{0.2133lp_{t-3}} + \underset{(4.6)}{0.03ler} + \underset{(3.3)}{0.02lm2} + \underset{(3.6)}{0.0129lwr}$$

adj $R^2 = 0.99$ SER = 0.011 $SC(\chi^2_1) = 0.0038$ D-F = -5.52

and the short run error correction model was

$$\Delta lp = \underset{(0.64)}{0.0009} + \underset{(5.9)}{0.94\Delta lp_{t-1}} - \underset{(-1.1)}{0.13\Delta lp_{t-2}} + \underset{(5.9)}{0.098\Delta ler}$$

$$+ \underset{(1.95)}{0.039\Delta lm2_{t-1}} + \underset{(1.4)}{0.005\Delta lwr} - \underset{(-2.9)}{0.51 ecm_{t-1}}$$

adj $R^2 = 0.60$ SER = 0.01 F(1, 183) = 45.3 $SC(c^2_1) = 3.3$
HET[F(27, 160)] = 1.4 RESET$(c^2_1)$=0.87

M1 was replaced by M2 in this monthly model as it was found to be more relevant. The model maintained the basic characteristics in the short run as Worrell's (1992) model.

It must be noted that whilst these models examine the determinants of inflation it may be argued that they do not fully explore the causal relationship between the variables. Simple correlation does not necessarily indicate causation. Against this back-ground, S. Nichols, J.Nichols and H.Leon (1995) investigated the money price causation in four CARICOM economies. Granger causation was found to run from base money and the narrow definition of money to prices between 1973 to 1995. This did not hold however for intervening periods. Causation from base money and broad money was found in the 1981 to 1989 period. Causation was found also to run from prices to broad money and M2. Ganga (1992) found no causal relation between prices, money supply and exchange rate using annual data from 1970 to 1990. Using monthly data from December 1990 to February 1992, however, he found significant unidirectional causality from money supply and exchange rate to prices.

The foregoing would suggest that whilst certain variables have relatively more influence on the behaviour of prices, the theoretical postulate underlying the behaviour of prices in the Jamaican economy remains partially obscure as the precise causal relations still require further analysis. VAR models as proposed by Sims (1980) circumvent these problems *initially,* as they do not impose strict theoretical priors. That is, VARs avoid any *a priori* endo-exogenous division of variables, consequently the Sims methodology is referred to by Cooley and LeRoy (1985) as atheoretical macroeconometrics. For short run forecasting purposes this approach avoids the need for explicitly forecasting the exogenous variables, a limitation of conventional models.

## III. Empirical Model and Results

### Variable Selection

The previous discussions on inflation and recent empirical work suggest that both monetary and to a lesser extent structural variables are relevant to the model. For parsimony, however, the variables selected are the logs of the consumer price index(CPI) (in which case the difference gives the inflation rate), exchange rate (xrate) , gross domestic product (GDP), imported price index[7] (ipi) to capture imported inflation, interest rate on Jamaican treasury bills (ijt) and the money base (bm). Imported inflation and GDP represent the structural influences on inflation whilst the interest rate on treasury bills and base money represents the monetary policy stance

Block exogeneity tests are used to determine how these variables enter the model. Block exogeneity tests are the multivariate generalization of the Granger causality tests. It has as its null hypothesis, that the lags of a set or block of variables do not enter the equations of the other variables, and thus it is exogenous to the model.

Tests for stationarity were conducted using the Phillips-Perron test. Like the Dickey -Fuller test, it tests the hypothesis that $\rho = 1$, however, the t-statistics of the coefficient is corrected for serial correlation, using the Newey-West procedure. All that is required is the autoregressive structure to be used by the Newey-West routine.

## Results

Table 4.1 shows the results of the unit root tests with the 5% Mckinnon critical values. The table shows that all the variables are non-stationary, specifically, the variables are I(1). Consequently they have to be differenced once to become stationary. Further Table 4.2 shows the results of the Johansen tests for cointegration amongst the variables. The results indicate that there are at most two cointegrating vectors.

**TABLE 4.1**
***Phillips-Peron Unit Root Test***

| Variable | Level | 1st Difference |
|---|---|---|
| LCPI | -1.25 | - 7.82 |
| LGDP | -2.19 | -10.77 |
| LIPI | -1.89 | -13.42 |
| LXRATE | -2.31 | - 9.37 |
| LBM | -3.21 | -16.25 |
| LIJT | -3.25 | -10.38 |

*MacKinnon 5% critical value = -3.4344*

**TABLE 4.2**
***Johansen Cointegration Test***

| | Eigenvalue | Likelihood Ratio | 5% Critical value | 1%Critical value |
|---|---|---|---|---|
| $r=0$ | 0.274 | 149.4 | 102.1 | 111.01** |
| $r\leq 1$ | 0.189 | 89.6 | 76.1 | 84.45 ** |
| $r\leq 2$ | 0.135 | 50.4 | 53.1 | 60.16 |
| $r\leq 3$ | 0.068 | 23.6 | 34.9 | 41.07 |
| $r\leq 4$ | 0.036 | 10.1 | 19.9 | 24.60 |
| $r\leq 5$ | 0.017 | 3.3 | 9.2 | 12.97 |

*(**) denotes rejection of the hypothesis at 5%(1%) significant level.

Given the above results a VECM was estimated. Because we are using monthly data an initial lag length of twelve lags (unrestricted VAR) versus smaller lags VARs was tested. Initially the Likelihood ratio favoured seven lags chosen. Further iterations however based on the likelihood ratio and the Schwartz criterion favoured a four lag VAR.[8]

The block exogeneity tests indicated that base money, interest rate, exchange rate and gross domestic product should enter the model at four lags. This would suggest that Granger causality runs from these variables to the inflation rate. The most significant variables were base money and exchange rates. The evidence for imported inflation was weak. It was replaced by wages, however, the out of sample forecasting accuracy of the VECM declined significantly. This is probably the result of a poor monthly wage series. Imported inflation, to the extent that its impact would reflect structural influences, was therefore retained in the model. The full VECM results are given in Appendix 4.1.

## FORECASTS

Table 4.3 gives a comparison of the forecasting accuracy of the VAR model against an ARMA(4, 3), Ganga's monthly model and the monthly version of Worrell's (1993) model. The criteria used are the root mean square error RMSE, Theil U statistics and the Janus quotient (J). The Janus quotient looks at the predictive accuracy of the out of sample predictions against the within sample fit. It is given as,

$$J^2 = \frac{\sum_{i=n+1}^{n+m} (P_i - A_i)^2 / m}{\sum_{i=1}^{n} (P_i - A_i)^2 / n}$$

The numerator gives the deviations in the out of sample period whilst the denominator gives the deviations over the sample period. The higher its value the poorer the forecasting performance. If the structure of the model remains constant over the out of sample period then J tends to one. Thus values greater than one indicates the presence of some structural change. This statistic and its interpretation are affected by the size of the out of sample period.[9]

The VAR model has the lowest mean square error in the predictions. Correspondingly it possesses the greatest predictive power as evidenced by the Theil U statistics. The ECM is only marginally better than the ARMA model in terms of its forecasting accuracy. Whilst the J-statistic for the VAR model is acceptable (at this point), the ECM exhibits the greatest structural stability. The other models are highly unstable. This highlights the important point that VAR models are suited for short-term forecasting (one to two years). Medium to long term forecast horizons require the use of models such as error correction models.

**TABLE 4.3**
**Comparison of Forecasting Accuracy**

| Model | RMSE | Theil U | J |
|---|---|---|---|
| VAR | 0.004 | 0.18 | 0.34 |
| ARMA | 0.008 | 0.38 | 5.22 |
| ECPM | 0.009 | 0.35 | 0.90 |
| GANGA | 0.036 | 1.70 | 2.40 |

## Impulse Response and Variance Decomposition

This section analyses the dynamic property of the model using variance decomposition and impulse response functions. Figure 1 shows the response of the inflation rate to a one unit shock to the exchange rate, base money, treasury bill rate, imported inflation and output. The x-axis gives the time horizon or the duration of the shock whilst the y-axis gives the direction and intensity of the impulse or the percent variation in the dependent variable (since we are using logs) away from its base line level.

Monte Carlo simulations (with one hundred draws) from the unrestricted VAR were used to generate the standard errors for the impulse response and variance decomposition coefficients. The confidence bands for the response function are 90 % intervals generated by normal approximation. There is no consensus on an explicit criterion for significance in a VAR framework. Sims (1987) however suggests that for impulse responses significance can be crudely gauged by the degree to which the function is bounded away from zero, whilst Runkle (1987) suggests a probability range above 10 percent for variance decompositions.

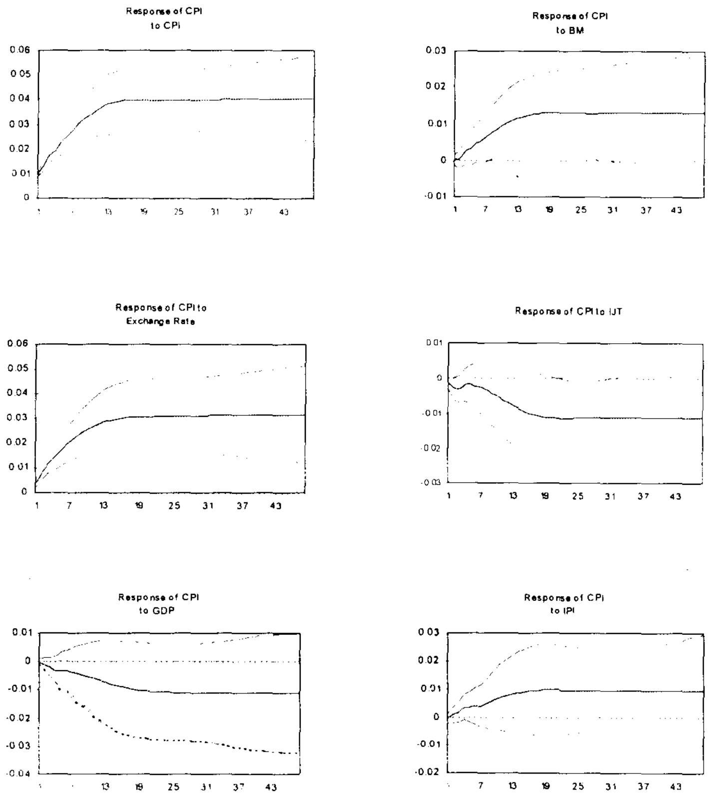
The impulse responses meet *a priori* expectations in terms of the direction of impact. The graphs show that a positive shock to monetary variables or expansionary monetary policy, has a significant expansionary effect on inflation. *The effect of a unit shock to base money on the cpi, occurs after approximately the first one to two months and reaching its peak between ten to twelve months.* Thereafter the cumulative effects of base money stabilize with the monthly CPI increasing by approximately one percent of its baseline level.

*The impact of the exchange rate is rather immediate and long lasting. A unit shock to the exchange rate causes the cpi in the first period to deviate by approximately 0.5 percent from its base level.* The inflation rate accelerates rather rapidly in the first ten to twelve months as the CPI tends to a new equilibrium level. *Increases in the interest rates tend to have a contractionary effect on prices.* The more significant impact, however, manifests itself after five months with the response function trending away from zero.

The response of direct shocks to the CPI such as expectations and discrete price adjustments resulting from increase markups and removal of subsidies, follows a similar path to the response to exchange rate shocks. The magnitude of the impact of direct shocks, particularly in the first period, is greater for direct shocks to the CPI. The similarity in the paths may stem from the fact that both sources represent some cost push element. The impulse response of CPI to its own innovation, however, does highlight the role of expectations and the price setting mechanism which includes indexation.

*Increases in output do have a significant contractionary effect whilst imported inflation exerts a positive influence after the second month.* The impact, particularly of imported inflation, seems to be long lived. This is due to the open nature of the economy and the extent to which domestic production relies on foreign inputs.

**FIGURE 4.1**
**Response of CPI to One Standard Deviation Shocks**



The foregoing indicates that both cost push and demand pull elements help to explain prices. Having shown the dynamic effects of each disturbance, however, the next step is to assess their relative contribution to the fluctuations in prices. This is done by decomposing the forecast variance of the inflation rate over different horizons.

Table 4.4 shows the variance decomposition over the short term (6 months), medium term (12 - 24 months) and over the long term (48 months). The statistics indicate the percentage contribution of innovations in each of the variables in the system to the variance of the CPI. *The results show that shocks to the CPI itself and the exchange rate accounts for most of the variability in the CPI over all horizons*. Not much can be attributed to base money, although over longer horizons its relative contribution increases. More importantly, the variance decomposition of the exchange rate (Table V) shows that apart from innovations to the exchange rate itself, base money contributes significantly to the variations in the exchange rate. This supports Ghartey (1995) assessment. *We can conclude that the basic transmission mechanism runs from base money (via interest rates which affect the relative return on financial assets) to the exchange rate and then to prices.*

Furthermore, the greater contribution of innovations in the exchange rate in Table 4.5 suggests that much of its volatility is the result of exchange rate speculation (even in the long run). One will also note the increasing contribution of the CPI over time. This maybe reflecting the long run phenomena of purchasing power parity (i.e feedback from the CPI to the exchange rate).

**TABLE 4.4**
*Variance Decomposition of the CPI (%)*

| Horizon | Base Money | CPI | IJT | Ex. Rate | IPI | GDP | Std. Err |
|---|---|---|---|---|---|---|---|
| 6 mths | 1.964 | 65.289 | 1.028 | 29.065 | 1.440 | 1.214 | 0.10237 |
| 12 mths | 3.724 | 59.966 | 1.325 | 31.585 | 1.931 | 1.469 | 0.14865 |
| 24 mths | 4.949 | 55.068 | 3.121 | 31.384 | 2.757 | 2.719 | 0.24518 |
| 48 mths | 5.257 | 52.967 | 3.716 | 31.654 | 2.92 | 3.487 | 0.38501 |

**TABLE 4.5**
*Variance Decomposition of the Exchange Rate (%)*

| Horizon | Base Money | CPI | IJT | Ex. Rate | IPI | GDP | Std. Err |
|---|---|---|---|---|---|---|---|
| 6 mths | 7.024 | 2.538 | 1.626 | 86.771 | 0.742 | 1.3 | 0.10237 |
| 12 mths | 8.414 | 6.361 | 5.889 | 73.484 | 2.177 | 3.674 | 0.14865 |
| 24 mths | 8.420 | 7.687 | 7.226 | 68.774 | 2.315 | 5.576 | 0.24518 |
| 48 mths | 8.43 | 8.9 | 7.511 | 66.245 | 2.399 | 6.417 | 0.38501 |

## IV. Conclusion

The foregoing points to increased forecasting accuracy when a VAR is applied as against other models. VARs avoid the need for an explicit theory (in the initial stages) and information on the exogenous variables over the forecast period. The foregoing results and the experience of a number of economists using VARs, however, suggest that VARs are more suited for short term forecasting. Simultaneous and single equation error correction models are more appropriate for longer horizons.

When applied to price behaviour in Jamaica, the VAR model revealed some interesting, though not surprising results, not readily seen with other conventional models. The innovation analysis showed that a positive shock to monetary variables or expansionary monetary policy has an unambiguous expansionary effect on prices. The response functions indicate that monetary policy has a lag effect of 'at least' two months. Furthermore, a decline in the rate of depreciation of the exchange rate will have an immediate dampening effect on prices, particularly in the first twelve months. The response to exchange rate shocks suggests that exchange rate stabilization maybe the most effective way of achieving price stability in the short run. The results of the variance decomposition suggest that monetary stability and the development of an efficient market are essential to exchange rate stability.

The results show that the prices rate do not return to its original level as there is a tendency for inflationary shocks to be long lived. These shocks maybe perpetuated by the nature of the stabilization process, the structure of the economy, the production function, indexation and other institutional factors. Other factors such as the pricing mechanism, expectations and exchange rate speculation, which are captured in the own innovations of the CPI and exchange rate are also very significant and create very strong inertial tendencies. Stabilization policies must therefore be cognizant of these influences that frustrate the stabilization process.

## NOTES

1. The views expressed in this paper are not necessarily those of the Bank of Jamaica.

2. Sims (1980), **Macroeconomics and Reality**, Econometrica vol.48 pg. 2

3. Ibid pg. 2

4. See for example Sims(1980), Rosenweig and Tallman (1993), Blanchard and Quah (1989) and Quah and and Vahey (1995).

5. See for example Worrell, Watson and Scantlebury - Mynard (1992).

6. Ghartey (1994) found that changes in the exchange rate can be linked to monetary dynamics. consequently he suggests that monetary policy can be employed to control the exchange rate.

7. Imported inflation is derived from an imported price index, which is a weighted average of the export prices of the major trading partners and the price of oil.

8. The Likelihood Ratio for twelve versus seven lags was c2 (112) = 91.1 with a significance level of 0.9267. At Four lags the Likelihood Ratio c2 (64)= 62.32 with a significance level of 0.536. We therefore cannot reject

the null hypothesis that the restrictions hold, and thus conclude that four lags are sufficient. The Schwartz criteria for 12, 7 and 4 lags were 46.3, 45.2 and 44.0 respectively.

9. A more appropriate test would be Chow's predictive test. However, the reduction in the sample size, given the number of parameters, would make it difficult to clearly distinguish between instability in the form of occasional outliers and instability in the form of parameter shifts.

## Appendix 4.1. VECM Results

| | Δlbm | Δlcpi | Δlijt | Δlxrate | Δlipi | Δlgdp |
|---|---|---|---|---|---|---|
| **CointEq1** | -0.075302 | 0.002964 | 0.146435 | 0.044753 | -0.020258 | -0.000165 |
| **$\Delta lbm_{-1}$** | -0.245188 | -0.011797 | -0.147164 | -0.030756 | 0.025457 | -0.005908 |
| **$\Delta lbm_{-2}$** | -0.159482 | 0.024389 | -0.306856 | 0.020044 | -0.031585 | -0.004351 |
| **$\Delta lbm_{-3}$** | -0.108646 | -0.001719 | -0.051006 | -0.028488 | -0.016533 | 0.003347 |
| **$\Delta lbm_{-4}$** | -0.100600 | 0.012345 | 0.065615 | 0.049860 | 0.009226 | -0.004181 |
| **$\Delta lcpi_{-1}$** | -1.142976 | 1.463842 | 1.368287 | -0.345637 | 0.115232 | -0.015698 |
| **$\Delta lcpi_{-2}$** | 0.280319 | 0.267643 | -0.629099 | 0.765135 | -0.578186 | -0.005017 |
| **$\Delta lcpi_{-3}$** | -1.001608 | -0.034955 | 1.396298 | -0.369185 | 0.638502 | -0.014165 |
| **$\Delta lcpi_{-4}$** | 0.409937 | 0.130851 | 0.395987 | 1.161784 | -0.253843 | 0.016390 |
| **$\Delta lijt_{-1}$** | -0.022102 | -0.010753 | 0.217460 | 0.048805 | -0.005227 | 0.001611 |
| **$\Delta lijt_{-2}$** | -0.006775 | 0.015486 | 0.170529 | 0.046596 | -0.037137 | -0.000613 |
| **$\Delta lijt_{-3}$** | -0.069554 | 0.019427 | 0.175152 | 0.018287 | -0.022962 | -0.000386 |
| **$\Delta lijt_{-4}$** | 0.016762 | 0.004149 | 0.029963 | -0.063263 | -0.038822 | -0.001489 |
| **Δlxrate** | 0.198067 | 0.083270 | -0.078436 | 0.475685 | -0.064791 | 0.001006 |
| **$\Delta lxrate_{-2}$** | -0.187667 | -0.021281 | 0.485300 | -0.246506 | 0.069509 | -0.000535 |
| **$\Delta lxrate_{-3}$** | 0.204625 | 0.029813 | -0.034784 | 0.210878 | -0.048689 | -0.000745 |
| **$\Delta lxrate_{-4}$** | 0.239359 | -0.010273 | -0.025574 | -0.014115 | -0.012678 | 0.000120 |
| **$\Delta lipi_{-1}$** | -0.102374 | 0.021819 | -0.074585 | -0.041263 | 0.147815 | -0.001770 |
| **$\Delta lipi_{-2}$** | 0.152281 | 0.012038 | -0.144849 | 0.059797 | -0.108635 | 0.004301 |
| **$\Delta lipi_{-3}$** | 0.085430 | 0.018808 | -0.136377 | -0.054082 | -0.082120 | -0.000415 |
| **$\Delta lipi_{-4}$** | -0.019440 | -0.022786 | -0.094716 | -0.021551 | -0.149414 | 0.000587 |
| **$\Delta lgdp_{-1}$** | -1.736537 | -0.185210 | -0.960204 | -0.269209 | 1.290785 | 0.379184 |
| **$\Delta lgdp_{-2}$** | 2.209432 | -0.245179 | 5.805997 | 0.292302 | 0.236400 | 0.169180 |
| **$\Delta lgdp_{-3}$** | -5.666179 | 0.104583 | -0.017186 | -0.367664 | -0.228389 | 0.095328 |
| **$\Delta lgdp_{-4}$** | -1.217771 | 0.326404 | -2.090249 | 0.498937 | 2.037606 | -0.005652 |
| **C** | 0.065352 | 0.002740 | -0.037944 | -0.011772 | 0.001324 | 0.001177 |
| **Adj. R-squared** | 0.175903 | 0.535369 | 0.283515 | 0.259193 | -0.005172 | 0.330951 |
| **Akaike AIC** | -5.502484 | -8.813576 | -5.141707 | -6.178165 | -5.859293 | -12.00361 |
| **Schwartz SC** | -5.05323 | -8.364331 | -4.692462 | -5.728920 | -5.410048 | -11.55437 |

# CHAPTER

# 5

# AN ALTERNATIVE APPROACH FOR THE ANALYSIS AND FORECASTING OF ECONOMIC SERIES: STATE SPACE MODELLING

*Alain Maurin*

# An Alternative Approach for the Analysis and Forecasting of Economic Series : State Space Modelling

*Alain Maurin*[1]

The enthusiasm for econometric research at the end of the 1980s has led today to a wide range of concepts for the description and analysis of economic variables, as well as, a wide variety of methods used in the modelling and forecasting of these variables.

Firstly, due to questions raised by Sargent (1979) and Sims (1980), VAR models have become quite popular in empirical studies. The causality tests and the impulse response functions have been widely used to test some theories, not only for precise questions such as the correlation between money and real activity, but also for more general questions such as the specification of macroeconomic models. The need to take into account the non- stationarity of time series have also led economists to dedicate an abundant amount of research to integration and cointegration tests. As such, these tests are now almost unavoidable when attempting to describe the individual and joint evolution of variables. The ARCH model which was introduced in this decade by Engle (1982) also allows one to take directly into account the temporal variation of the variance of the various series.

Among all the developments made recently, there is also a renewed interest in state space modelling. Indeed, after the successes of the famous Kalman filter in numerous applications of systems theory, Akaike (1974) and Aoki (1976) suggested that this approach be applied to the study and forecast of economic series.

The majority of economists did not adopt it, however, because it seemed difficult to apply not only because of the choice of the parameters of the Kalman filter but also because of the complex calculation formulas.

The change of opinion about the use of the state space framework for the study of economic series is a result of the new methodology proposed by Aoki (1987,a). Based on the notion of "balanced realization", it sought to build a state model directly from studied data. In this respect, the approach is likely to be used more intensely in the future than it is today. This is particularly true since it suits the forecasting of univaried series, as well as, the analysis of the joint dynamics of several series. Empirical studies in the recent econometric literature illustrate the wide range of applications possible in the state space framework. For univariate series, Kohn and Ansley (1985,1986) elaborated algorithms of estimation, interpolation and forecasting for series which might have missing data. Shea (1987,1989) proposed a procedure that would allow the calculation of the likelihood function of an ARMA process from the state space formulation. As another example, Barone (1987) developed a method that generated stationary multivariable Gaussian series relying on a state representation. Applications are also numerous for multivariate series. For example, Aoki (1987,b) studied the interdependence between economic variables in Japan and the USA and showed that state space modelling leads to more accurate interpretation and analysis, compared to VAR models. Another example is Vinod and Basu's (1995) state model for consumption, income and interest rates. Using American data, they estimated the model and used it to argue for a different point of view on the empirical investigation of business cycle theory.

Considering the quality of results this model has already provided, state space modelling offers good prospects for empirical research; not only for its desirable statistical properties but also because this approach provides a good empirical tool for the study and forecasting of macroeconomic variables. Indeed, a study of the evolution of variables and research on optimal economic policies can be undertaken in a rich methodological framework, based on the concepts of systems theory. This framework allows for the identification and specification of a model, the analysis of the dynamic properties of this model and the simulation of optimal control laws (Pagan and Preston (1982), Maurin (1993)). In the same way, the fact that state space models are asymptotically stable (Aoki (1987,b)), make it possible to argue that the forecasts results are more reliable than the ones supplied by VAR models.

Initiated at the beginning of the 1970s, the work dedicated to macroeconometric modelling in the Caribbean has led today to the existence of a rather wide range of models. But as Craigwell *et al* (1995) have stressed, many of these models have some deficiencies regarding their theoretical specification. An assessment of their importance for policy development also indicates that few if any of them were actually used for the development of economic policies and the calculation of forecasts.

Since data on several key variables are missing or are only available for relatively short periods, and only in annual periodicity, it is obvious that the deficiencies of the statistical systems in Caribbean countries is the reason for this rather unfortunate situation.

In light of this, we need to identify some alternatives. Are there solutions which other modelling approaches could provide? The objective of this paper is, therefore, to examine the contribution that state space modelling could make in the field of modelling and forecasting of Caribbean economic variables.

Our paper is organized as follows, the first section deals with the problem of identifying a space structure directly from observed data and the estimation of its parameters. In the second section, the implementation of the method is illustrated with particular emphasis on the treatment of Caribbean series.

## 1. Identification of the Model and Estimation of its Parameters

The minimization of a quadratic criterion under the constraint of a linear system and the estimation by Kalman filter have been, until the end of the 1980s, the type of problems in control theory which gave rise to many applications in economics. Since the formulation of Aoki (1987), which aims at leading to a state model directly from observed data, the identification of a multivariate system represents another important aspect of control theory to be the subject of economic applications.

In the context of systems theory, the identification of a system consists of determining a state model, that is to say a quadruplet $(A_t, B_t, C_t, D_t)$ of minimal size which has to be compatible with the known data of the input and output variables. Before the 1980s, one could discern three basic approaches : the method resulting from least squares, the maximum likelihood method and the instrumental matrix method (see Doncarli and Larminat (1978) for a survey). Over the years, the methods deriving from the concept of "balanced realization" introduced by Moore (1981) asserted themselves (see for example Verhaegen and Depprettere (1991), Van Der Klaw et al. (1991), Ljung (1991)).

Aoki (1987) was the first economist to make a contribution to the problem of the identification of an economic system. However, Akaike (1974) is the one who introduced a state space parametization for modelling time series. Similar to the one which is used in the Kalman filter, this parametrization has a drawback, it leads to different and non-equivalent models when the size of the state vector is modified. By writing a state model in the so-called innovation form and relying on the balanced realization technique, Aoki established a procedure which supplies a single state representation of minimal size. This procedure relies on the singular value decomposition of a Hankel matrix built from the autocovariance function of each series.

After Aoki, the work of other researchers led to different methods. For example, Otter and Van Dal (1987) formulated a variant which uses a Hankel matrix defined from the covariances between the innovations and the studied data. Mittnik (1989) also studied several identification schemes from a state representation in which the state vector is brought up to date from the output observed at instant $t$, instead of the innovation at this same instant. As another variant, Havenner and Criddle (1987) suggested a procedure which relies on a Hankel matrix built from centred and reduced data.

Although these methods have their specific peculiarities, they all operate in two stages: obtaining a Hankel matrix and then calculating the parameters of the model by applying the results of system theory.

## 1.1. The procedure for parameter estimation

Let $\{y_t; t = 1, \ldots, N\}$ be a set of centered and stationary observations of a $y$ vector which regroups $q$ variables representating the evolution of an economic phenomenon observed at the instants $t = 1, \ldots, N$ and let the innovation form[2] be :

$$\begin{cases} z_{t+1} = Az_t + Ge_t \\ y_t = Cz_t + e_t \end{cases} \tag{4}$$

where the innovations $e_t$ are both serially independant with covariances $\Delta_e$ and independant of state variables $z_t$ $(Cov(z_t, e_t) = 0; \forall t, l)$.

The usual procedure to determine the parameters $(A, G, C)$ which "realize" the system (4) is composed of the following stages.

### Construction of the Hankel matrix

Let us note $\Delta_k = Cov(y_t y_{t+k})$ the covariance matrix between $y_t$ and $y_{t+k}$. We have :

$$\begin{aligned} E\{y_t y'_{t+k}\} &= E\{(Cx_t + e_t)(Cx_{t+k} + e_{t+k})'\} \\ &= CE\{x_t x'_{t+k}\}C'E\{x_t e'_{t+k}\} + E\{e_t x'_{t+k}\}C' + E\{e_t e'_{t+k}\} \end{aligned}$$

Since $E\{e_t x_{t-k}\} = 0 \forall t$ and $e_t$ is not autocorrelated, we get :

$$\Delta_k = \begin{cases} C\Pi C' + \Delta_e & \text{if } \ k = 0 \\ CA^k \Pi C' + CA^{k-1} G\Delta_e & \text{for } k = 1,2,\dots t \end{cases} \tag{5}$$

with $\Pi = E\{x_t, x_t'\}$ and $\Delta_e = E\{e_t, e_t'\}$

Indeed, when $k = 0$ the relation above is obvious. For $k \geq 1$, we develop the transition equation of the model (4). We obtain

$$x_{t+k} = A^k x_t + \sum_{j=0}^{k-1} A^{k-j-1} G e_{t+j} \tag{6}$$

which allows us to write :

$$E\{x_t, x_{t+k}'\} = A^k E\{x_t, x_t'\} = a^k \Pi \tag{7}$$

Since $s = t + k$, (6) becomes :

$$x_s = A^k x_{s-k} + \sum_{j=0}^{k-1} A^{k-j-1} G e_{s-k+j}$$

We deduce that $E\{x_t, e_{t+k}'\} = A^{k-1} G$

Generally, one would use a Hankel's hypermatrix to represent a finite or infinite series of matrices. With the autocovariance function $\{\Delta_k\}$, we get this hypermatrix $H$ in the following way :

$$H = \begin{bmatrix} \Delta_1 & \Delta_2 & \Delta_3 & \Delta_4 & \cdots \\ \Delta_2 & \Delta_3 & \Delta_4 & . & \cdots \\ \Delta_3 & \Delta_4 & \Delta_5 & . & \cdots \\ \Delta_4 & . & \cdots & . & \\ . & . & \cdots & . & \\ . & . & \cdots & . & \\ . & . & \cdots & . & \end{bmatrix} \tag{8}$$

From the observations $\{y_t; t = 1, \ldots, N\}$, we can calculate an approximation $\hat{H}$ of $H$ in many different ways. The one which is directly deduced from the autocovariance matrices is defined by:

$$\hat{H} = \begin{bmatrix} \hat{\Delta}_1 & \hat{\Delta}_2 & \cdots & \hat{\Delta}_r \\ \hat{\Delta}_2 & \hat{\Delta}_3 & \cdots & . \\ . & . & \cdots & . \\ . & . & \cdots & . \\ . & . & \cdots & . \\ \hat{\Delta}_f & \hat{\Delta}_{f+1} & \cdots & \hat{\Delta}_{f+r-1} \end{bmatrix} \tag{9}$$

$r$ and $f$ being respectively the number of block-columns and the number of block-lines by columns, and $\hat{\Delta}_i$ an estimator of $\Delta_i$.

Because of the stationarity of the process $\{y_t\}$, $\hat{H}$ coincides with the estimator of the matrix

$$E\left\{\begin{bmatrix} y_{t+1} \\ y_{t+2} \\ \cdot \\ \cdot \\ \cdot \\ y_{t+f} \end{bmatrix} \begin{bmatrix} y'_t \, y'_{t-1} \cdots y'_{t-r+1} \end{bmatrix}\right\},$$

that is to say the autocovariance matrix between observed values of the variables $y_t$ and the future realisations of these variables $(y_{t+1}, \cdots, y_{t+f},)$, calculated from the present and past observations of $y$. In that case, $r$ indicates the maximum lag to represent the memory of the process and $f$ is an integer wich depends on the horizon of prediction $h$ $(f \geq \max(pr, h))$.

An unbiased estimator of $\Delta_i$ is

$$\hat{\Delta}_i = \frac{1}{N-i} \sum_{t=1}^{N-i} y_{t+i} y_t, i = 0, 1, \ldots, r+f.$$

However, it is advisable to choose the quantity $\hat{\Delta}_i = \frac{1}{N} \sum_{t=1}^{N-i} y_{t+i} y_t$ which corresponds to the maximum likelihood estimator of $\Delta_i$.

## Choice of the model order

By definition, the state vector is interpreted as the memory of the system, it synthetizes all the information on its past evolution. In relation to the particular structure of the Hankel matrix, this information corresponds in some respects to relationship measures between the past and the future values of the variables. It is therefore particularly suitable for the forecasting of the future values of $y_t$ from its past observations. We then understand that the quality of adjustment of a state model from observed data of $y_t$ and the quality of the forecasts $y_{t+i}$, $i = 1,2,\ldots$ depend on the chosen value for the number of components of the state vector.

This choice is made firstly by deciding the values to give to the parameters $r$ and $f$. Inadequate values of these lag parameters can lead to misspecified models in multivariate systems. Indeed, small values do not capture enough of the information contained in the autocovariance function as is desirable. Inversely, large values entail a minimal loss of information in the approximation of $H$ by $\hat{H}$ but, in return, generate greater errors. Thus, the number of states $n$ that can synthetize the information contained in $\hat{H}$ is given by the rank of this matrix defined as the number of nonzero singular values of $\hat{H}$ (Kronecker theorem).

## Calculation of the matrices $\hat{A}$, $\hat{G}$ and $\hat{C}$

We calculate the estimators $\hat{A}$, $\hat{G}$ and $\hat{C}$ by performing two factorizations of the matrix $\hat{H}$.

Firstly, the structure of the matrices $\Delta_k$ defined in terms of the parameters of the model (4) and of the covariances $\Pi$ and $\nabla_k$

enables the matrix $H$ to have the following remarkable property :

$$H = \begin{bmatrix} C \\ CA \\ \cdot \\ \cdot \\ \cdot \\ CA^{f-1} \end{bmatrix} \begin{bmatrix} \Omega & A\Omega & \cdot & \cdot & \cdot & A^{r-1}\Omega \end{bmatrix} \tag{10}$$

$H$ is writen as the product of the observability matrix by a matrix whose form is similar to that of the commandability matrix of system (4). From relations (5) and (10), we can establish the expression of $\Omega$ :

$$\Omega = A\Pi C' + G\Delta_e \tag{11}$$

Since $C$, $A$ and $\Omega$ are unknown but $H$ can be estimated, we deduce from its singular values decomposition :

$$\hat{H} = \hat{O}\hat{C} = \hat{U}\hat{\Sigma}\hat{V} \tag{12}$$

Equality permits several factorizations for $\hat{O}$ and $\hat{C}$ . We can have for example $\hat{O} = \hat{U}'$ and $\hat{C} = \hat{\Sigma}\hat{V}'$ or $O = \hat{\Sigma}^{1/4}\hat{V}'$ and $\hat{C} = \hat{\Sigma}^{3/4}\hat{V}'$ . Among these factorizations, Moore (1981) showed that the most interesting is the one which implies the equality of the gramians

$$\hat{O}\hat{O} = \hat{C}\hat{C} = \Sigma \tag{13}$$

and the derivation of these serve as the unique solution of Lyapunov[3] equations.

$$\begin{aligned} A'XA - X &= -C'C \\ AXA' - X &= -\Omega\Omega' \end{aligned} \tag{14}$$

It is defined by the relations (15) below and comes down to carrying out a change of basis in the state space to obtain a so called balanced rep[illegible]ntation :

$$\hat{O} = \hat{U}'\hat{\Sigma}^{1/2} \qquad \hat{C} = \hat{\Sigma}^{3/4}\hat{V}' \tag{15}$$

With this decomposition, the estimators of the parameters are obtained in two stages. Firstly, we show that $\hat{A}$, $\hat{\Omega}$ and $\hat{C}$ are given by :

$$\begin{aligned} \hat{A} &= \Sigma^{-\frac{1}{2}} U^t \bar{H} V \Sigma^{-\frac{1}{2}} \\ \hat{\Omega} &= \Sigma^{-\frac{1}{2}} U^t H^{\Omega} \\ \hat{C} &= H^C V \Sigma^{-\frac{1}{2}} \end{aligned} \tag{16}$$

the matrices $H^C$ , $H^{\Omega}$ and $\bar{H}$ being defined as follows :

$$H^C = \begin{bmatrix} \hat{\Delta}_1 & \hat{\Delta}_2 & \cdots & \hat{\Delta}_r \end{bmatrix} \tag{17}$$

$$H^{\Omega} = \begin{bmatrix} \hat{\Delta}'_1 & \hat{\Delta}'_2 & \cdots & \hat{\Delta}'_f \end{bmatrix} \tag{18}$$

$$\bar{H} = \begin{bmatrix} \hat{\Delta}_2 & \hat{\Delta}_3 & \cdots & \hat{\Delta}_{r+1} \\ \hat{\Delta}_3 & \hat{\Delta}_4 & \cdots & \hat{\Delta}_{r+2} \\ . & . & \cdots & . \\ . & . & \cdots & . \\ . & . & \cdots & . \\ \hat{\Delta}_{f+1} & \hat{\Delta}_{f+2} & \cdots & \hat{\Delta}_{f+r} \end{bmatrix} \tag{19}$$

Secondly, we calculate $\hat{G}$, using the matrix $\Pi$, the solution of the equation (20) obtained from (11):

$$\Pi = A\Pi A' + G\Delta_e G' \tag{20}$$

From relation (5) and the definition of $\Omega$ we obtain the following Riccati equation which ensure the stationarity of the process $\{x_t\}$.

$$\Pi = A\Pi A' + (\Omega - A\Pi C')(\Delta_0 - C\Pi C')^{-1}(\Omega - A\Pi C')' \tag{21}$$

Its resolution is made possible by an iterative algorithm which initialyzes the matrix $\Pi$ to the zero matrix and which achieves its updating directly from relation (21). Another process is based on a non-iterative algorithm similar to the one introduced by Laub (1983). It proceeds within two stages. First the construction of a symplectic matrix from the estimated parameters, then the

calculation of the solution from the transformation of this matrix into the real Schur decomposition form (Aoki (1987,a)).
Once this solution is found, the estimator of $\hat{G}$ is deduced from (11):

$$\hat{G} = (\Omega - A\Pi C')(\Delta_0 - C\Pi C')^{-1} \tag{22}$$

When the series is univariate, we can immediately underline some characteristics of the estimated parameters.

Firstly, since the Hankel matrix is symmetrical, its singular values decomposition implies that $U = \Sigma V$ with $\Sigma^2 = I$. Consequently, $C$ and $\Omega$ are defined in such a way that $C' = \Sigma\Omega$. For the matrix $A$, one can prove that each coefficient $a_{ij}$ verifies the equality $a_{ij} = \pm a_{ji}$. Lastly, if $n = 1$, the Riccati equation leads to a quadratic equation.

## 1.2. Properties of the Estimated Model

The principle of the procedure outlined above consists in extracting the essential of the information contained in the Hankel matrix by approximating the space spaned by this matrix by a space of lower dimension spaned by the singular vectors associated with the non-zero singular values. Taking advantage of the concepts and tools of systems theory, it naturally provides a model with salient properties which are of two orders.

First, specific properties stemming directly from the coordinate system and the algebraic transformations chosen to project the initial variables in the state space.

- The strict nestedness and the orthogonality of the models associated to the subspaces included into the state space. The states are chosen in such a way so that any model ($\hat{A}^*, \hat{G}^*, \hat{C}^*$) of dimension $n^*$ less than $n$ gets directly nested inside the models of superior size. Therefore, ($\hat{A}^*, \hat{G}^*, \hat{C}^*$) is obtained straight away by extraction of the $n^*$ first columns of $\hat{A}$, $\hat{G}$ and $\hat{C}$.

- The parametrization defined by the transformation (16)-(22) enables us to identify in a unique way the matrices $\hat{A}$, $\hat{G}$ and $\hat{C}$. It ends up in a state vector whose components are completely obtainable and observable. This state vector is also of minimum size, the space associated to it is the same as the smallest subspace spaned by all the past and future observations of the system output.

- $\hat{G}$ is the gain matrix of Kalman filter associated with model (4). It is well known that this filter provides the optimal estimation of the state variables which are not observable but whose knowledge is prior to the calculation of forecasts of the variables $y_t$ (see Anderson and Moore (1979)). In this filter, it is the coefficients of the matrix $\hat{G}$ which determine the weighing to attribute to the forecasts errors which occur in the calculation of the best prediction of state variables :

$$\hat{x}_{t+1|t} = \hat{A}\hat{x}_{t|t-1} + \hat{G}_t(y_t - \hat{C}\hat{x}_{t|t-1}) \qquad (23)$$

Besides these properties of stability and minimality, it is advisable to notice that the techniques involved in this procedure lead to a model which enjoys some general properties which were very useful in describing and correcting for the dynamic behavior of variables.

- The model is asymptotically stable if the initial series are weakly stationary. As we showed previously, this result is the direct consequence of restrictions imposed on the form of the observability and commandability matrices $\hat{O}$ and $\hat{C}$. Such a property is not guaranteed by the VAR methodology.

- We can consider that most of the forecasting models, for univariate, as well as multivariate series, constitute particular cases of state space models.

- Since the Kalman filter is the most effective among the adaptative estimation algorithms, state space models have the flexibility to deal directly with gross data of time series and, to take into account the non-stationarity arising from trend and seasonality.

In concluding the discussion on the characteristics of the procedure, we should mention that in other fields of investigation state space models have good prospects. For example, we think that it is possible to elaborate a variant of Aoki's procedure which would provide a cointegration test. The justification of this comes from the fact that the number of state $n$, obtained by selection of the non-zero singular values, is equal to the number of cointegration relations between the components of $y_t$. A definite use for such a test could be as an alternative to the Johansen and Juselius (1990) procedure. This alternative can be very useful since we know that on the numerical level, is it better to formulate a rule of decision on the basis of singular values rather than on the basis of eigenvalues.

### 1.3. Forecasts Computation

Once the realization $(\hat{A}, \hat{G}, \hat{C})$ is known, one can predict the values of the series $\{y_t\}$ in many different ways. We note $\hat{y}_{t+h|t}$ the forecast performed on the date $t$ for the horizon $h$.

The more convenient method consists in obtaining the $\hat{y}_{t+h|t}$ by solving the system (4) from an estimation of the initial state $x_1$. The latter can be obtained by the backcasting tehnique of Box and Jenkins, which is an iterative process calculating successively backwards forecasts and forwards forecasts. On the basis of the recurrence

$$\begin{cases} \hat{x}_{t+1} = \hat{A}\hat{x}_t + \hat{G}\hat{e}_t \\ \hat{e}_t = y_t - \hat{C}\hat{x}_t, \quad t = 1, \ldots, N-1 \\ \hat{x}_0 = 0 \end{cases} \tag{24}$$

we obtain firstly an estimation of $x_T$ by looking further back in time. Then from this estimation $\hat{x}_T$, we calculate forecasts backwards untill we get to $\hat{x}_1$ whose value is given by

$$\hat{x}_1 = \hat{G}\hat{e}_t + \sum_{i=1}^{N-1} (-1)^i \hat{A}^i \hat{G}\hat{e}_{1+i} \tag{25}$$

## 1.4. Computer Implementation

With respect to their properties and links with other models, it appear that state space models offer various techniques which are useful to forecasters.

Paradoxically, these techniques are still absent from the main econometric software for the treatment of times series such as RATS (windows version), micro-TSP (version 7), SORITEC, SAS PC Forecast, BMDP/PC and FORECAST MASTER. Even if some offer a few commands for modelling by state variables or the application of Kalman filter, the fact remains that a standard procedure for the identification and estimation of Aoki's method, as well as its variants, is not available yet in these programmes.

In this respect, the development of a tool which would contribute to a wider use of state space models for the analysis and forecasting of economic variables, seems to be a pressing necessity. In our opinion, there are two possible solutions. Firstly, using the CATS programme of Johansen and Juselius (1992) for cointegration tests, by developing a "state space module" within this programme. This approach has been adopted by Dorfman who proposed to specify state space models by introducing some a-priori knowledge in the selection and estimation of the parameters by means of distributions of probabilities. For the implementation of this Bayesian approach, they developed a Gaussian programme by using Speakeasy which is a powerful mathematical software package. Havenner (1997) has also proposed another programme which is relatively complete and which implements all the techniques described in the standard Aoki method.

The second solution consists in conceiving and writing a software programme dedicated to the application of the state space modelling concept directly with a programming language. Through it may seem more tiresome, such an approach offers the advantage of a large range of procedure choices when compared to the use of a standard software programme.

Whatever the case, resorting to programming reveals itself to be unavoidable for anyone who would like to use state space models. It is in this respect that we have have written a set of Pascal programmes in order to obtain accurate estimators of the models parameters and to compute forecasts. Also, we use the first rule of good programming, that is, we select algorithms which have good numerical performances. Thus, we have systematically chosen the algorithms which have the properties of numerical stability. In particular, the Gauss algorithm with full pivoting for matrix inversion, the Golub and Reinsh algorithm (see Forsythe *et al* (1977)) for the decomposition into singular elements and the Willkinson algorithm based on QR iterations with double implicit translation for the factorization in Schur form.

For the validation of a program, it is normal to carry out sets of tests which allow one to compare the results supplied by this program with some well known solutions. On the basis of the empirical tests that we have carried out, for the procedures of matrix numerical calculation previously mentioned, as well as, for the ones associated with different stages of the state space method, we could conclude that our programmes are valid.

## 2. Applications to Some Caribbean Variables

A national economy is too complex for us to pretend to describe it precisely, and even worse, to try to forecast the evolution of all the data and phenomena which characterize it. Thus, models and forecasts are usually developed for key variables representative of economic activity. These are the main aggregates of the real sphere of economic activity, the main prices and the main monetary and financial variables. In industrialised countries, this task is carried out by various public or private organisations which regularly publish general results targetting a large audience, as well as, specific results required by government officials.

As far as the Caribbean is concerned, an inventory of economic model building in the region reveals deficiencies in many areas. It is true that great efforts have been made since the 1970s to redress this problem and it has resulted in the awareness that there is a need to build operational models that could enlighten economic development policy. However, important obstacles still persist. One just has to ask the following questions to illustrate this situation. With a potential of about ten models for Jamaica, Barbados, Guyana and Trinidad and Tobago, how many of these models have actually been used for the evaluation of economic policy? Apart from the private sector and banks in particular, can it be asserted that Caribbean decision-makers are committed to the execution of studies for the development and evaluation of economic policy?

Therefore, ministries as well as in large companies, take important decisions in an environment of almost total uncertainty. Econometric studies based on forecasts and simulations, complemented if necessary by expert opinion, is an important tool for decision-makers. For example, the oil industry now makes up about 50% of the export volume and nearly 40% of state resources in Trinidad and Tobago. The forecasting of oil prices on the international market is, therefore, critical for planning. In the same way, revenues generated by tourism depend on the overall international tourism market. Market indicators in the tourism industry is, therefore, of dramatic importance to most Caribbean countries and consequently, forecasting variables that describe the number, the length of stay and the expenses of the tourist should be readily available.

These examples indicate that a quantitative analysis on the basis of a conventional structural econometric model alone is a tricky exercise, since quarterly or monthly time series of the most significant explanatory variables are not available. Moreover, time series of numerous Caribbean economic variables are missing totally or have missing observations, are too short or do not have the right periodicity (Watson (1995)). Faced with this situation, the question of how to deal with this statistical deficiency naturally crops up.

In another article published in 1995, Watson also raised the thorny issue of a cointegrated simultaneous equation model. We share his point of view concerning the adoption of a pragmatic approach, which consists of using a method that works. In this respect, it seems logical to seek a solution to this problem from among time series methods.

Applications for the forecasting of Caribbean macroeconomic variables have already been developed by some authors. To name just one, Greenidge (1995) adjusted different models related to exponential smoothing and Box-Jenkins methodology in order to develop forecasts of the Barbadian money supply.

However, if we refer to the econometric literature, it could be said with some justice that among the methods of time series analysis, VAR models constitute the most interesting tools for forecasting. Concerning their efficiency, numerous works have shown that they yield comparable, if not superior results to those generated using alternative methods (Wallis (1989), Doz and Malgrange (1992), Clément and Germain (1993)).

This conclusion is also valid for the state space models since this approach represent a generalisation of VAR models and, therefore, one can switch from one to the other easily (Aoki (1987)).

A good way to determine the empirical behaviour of an econometric method is to perform experiments on time series with various configurations : univariate or multivariate; short or long data periods; annual, quarterly or monthly periodicity; stable or volatile data. In this second section, therefore, we apply the state space method to the following data :

- monthly data on the number of tourists visiting Barbados between January 1992 to April 1995.
- a quarterly sample of money ($m_t$), the index of industrial production ($y_t$) and the index of consumer prices from the first quarter of 1973 to the third quarter of 1994.

- The annual vector $(y_t \;\; c_t \;\; i_t \;\; x_t \;\; m_t)'$ of GDP, private consumption, investments, exports and imports for Trinidad and Tobago.

## 2.1. The Tourism Example

On an international level, as well as on a more restricted level, be it for a country or for a geographical zone, the tourism industry has seen sustained development. This has become more pronouced over the past few years with the easing of restrictions on air transport. If we rely on OMT statistics, the total nomber of tourists arrivals increased from 60 million in 1960 to 284 million in 1980, before reaching 528 million in 1994. In the same way, receipts increased from 7 billion US dollars in 1960 to 103 billion in 1980 and 341 billion in 1994. An examination of international statistics also shows that tourism ranks first among the various categories of exchanged services, far ahead of petrol and the automobile industry. For industrialized countries (which mainly benefit from the receipts of international tourism), this sector is important in terms of employment, consumption and investment. For most other countries and especially for Caribbean countries, the development of tourism is obviously considered as a strategy for economic development. On this point, we note that those Caribbean countries which have experienced the highest growth rates over the past few years are those which opted for a policy of development that gives a central role to tourism.

These brief observations indicate how important it is to undertake research aimed at measuring the macroeconomic impact of tourists arrivals in a country and the forecasting of this variable. Concerning the forecasts horizon, Witt and Witt (1995) have argued, "short term forecasts are required for scheduling and staffing, medium term forecasts for planning tour operator brochures and long term forecasts for investment in aircraft, hotels and infrastructure".

Studies relating to the forecasting of tourism demand are relatively abundant in the literature. These studies centered principally on the specification of behavioural relations which sought to explain the determinants of tourism demand. In an effort to improve the forecasts precision, various methods for time series analysis were used. For example, González and Moral (1995) have suggested the use of a model of decomposition including an indicator of revenue, two prices indices, a stochastic trend and a stochastic seasonal component, in order to explain the tourism demand for Spain. For a comprehensive review of these studies we refer to the literature review of Witt and Witt (1995).

In the case of Caribbean countries, however, the number of these studies are still relatively small. Specifically, Rosensweig (1988) tested several specifications to analyse how prices affect tourism demand in some Caribbean countries. More recently, Whitehall and Greenidge (1996) have tested cointegrated relations to examine the problem of tourism activity in Barbados and Bermuda.

As an indicator of tourism activity, we use the monthly series of the number of tourists who visited Barbados over the period January 1986 to July 1995. Of course, the indicators measuring tourism activity in a country are usually affected by seasonal variations. For this Barbadian series we know that its seasonality can be describe by a deterministic seasonal pattern (Maurin (1995)). However, we kept the unadjusted data and opted for applying the method on centred data.

The sample covariances are:

$$\hat{\Delta}_0 = 35.5278; \hat{\Delta}_1 = 12.7127; \hat{\Delta}_2 = -4.8557; \hat{\Delta}_3 = 3.7732; \hat{\Delta}_4 = 11.1539; \hat{\Delta}_5 = 3.4644;$$

$$\hat{\Delta}_6 = -7.3875; \hat{\Delta}_7 = -0.0856; \hat{\Delta}_8 = 7.8469; \hat{\Delta}_9 = 1.6856; \hat{\Delta}_{10} = -7.4037$$

With $r = 5$, the $5 \times 5$ approximate Hankel matrix and its singular values are given by

$$\hat{H} = \begin{pmatrix} 12.713 & -4.856 & 3.773 & 11.154 & 3.464 \\ -4.856 & 3.773 & 11.154 & 3.464 & -7.388 \\ 3.773 & 11.154 & 3.464 & -7.388 & -0.086 \\ 11.154 & 3.464 & -7.388 & -0.086 & 7.847 \\ 3.464 & -7.388 & -0.086 & 7.847 & 1.686 \end{pmatrix}$$

$\sigma_i$ : 23.7710 19.2921 14.49998 2.4334 0.1381

There is a gap from the third value to the fourth value which suggest that we should retain 3 state variables to adequately synthetize the dynamic evolution of $y_t$. Results of our Pascal programme are reported in Table 5.1. They show that the estimator properties in the particular case of a scalar series are desirable. Figure 5.1 illustrating comparison of actual and in-sample forecast values suggest the model performed creditable, especially in view of the great fluctuations in the observed number of tourists.

## TABLE 5.1. ESTIMATION RESULTS WITH $\hat{n} = 3$

**Coefficients**

| | $\hat{A}$ | | $\hat{G}$ | | $\hat{C}$ | |
|---|---|---|---|---|---|---|
| -0.2313 | 0.8876 | 0.0895 | -0.0393 | -3.2395 | -1.2974 | -1.9194 |
| -0.8876 | 0.1571 | 0.4531 | 0.0863 | | | |
| 0.0895 | -0.4531 | 0.6909 | -0.0736 | | | |

**Covariances**

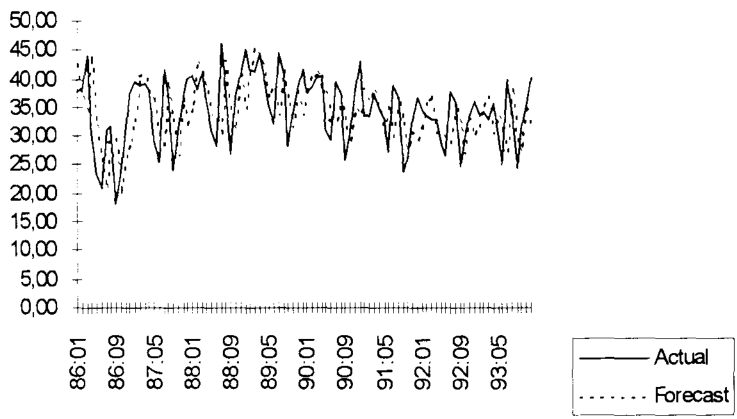
| $\hat{\Pi}$ | | | $\hat{\Delta}_e$ | | $\hat{\Delta}_0$ |
|---|---|---|---|---|---|
| 0.7010 | | | 75.0302 | 35.5278 | |
| 0.1671 | 0.5908 | | | | |
| 0.0259 | 0.0861 | 0.3647 | | | |

**Summary Statistics**[4]

| AVERAGE | MAD | FPE | RMSE |
|---|---|---|---|
| -0.0447 | 4.4382 | 29.8202 | 5.4608 |

TIME PLOTS OF ACTUAL AND IN-SAMPLE FORECAST VALUES

**FIGURE 5.1. NUMBER OF TOURISTS**




## 2.2. THE MONEY AND OUTPUT DATA FOR BARBADOS

Specification of models aiming to analyse the relationships between money and output in Barbados lead immediately to issues concerning the controversy surrounding realist and monetarist interpretrations of business cycles. As an alternative empirical strategy to shed a light on the explanations of the money-output correlation, state space models could be very useful. However, we focus our interest only on the question of forecasting these variables by taking account of the feedback among them.

We have conducted our estimation exercice on the basis of 88 quarterly observations which cover the period 1973:1 to 1994:4. Chosing 4 lags, we then stacked the sample estimates of autocovariance function to give rise to the following $8 \times 8$ Hankel matrix :

$$\hat{H} = \begin{pmatrix} \begin{pmatrix} 0.957 & 0.478 \\ 0.456 & 0.784 \end{pmatrix} & \begin{pmatrix} 0.925 & 0.454 \\ 0.417 & 0.739 \end{pmatrix} & \begin{pmatrix} 0.893 & 0.435 \\ 0.378 & 0.582 \end{pmatrix} & \begin{pmatrix} 0.864 & 0.432 \\ 0.337 & 0.603 \end{pmatrix} \\ \begin{pmatrix} 0.925 & 0.454 \\ 0.417 & 0.739 \end{pmatrix} & \begin{pmatrix} 0.893 & 0.435 \\ 0.378 & 0.582 \end{pmatrix} & \begin{pmatrix} 0.864 & 0.432 \\ 0.337 & 0.603 \end{pmatrix} & \begin{pmatrix} 0.837 & 0.432 \\ 0.280 & 0.458 \end{pmatrix} \\ \begin{pmatrix} 0.893 & 0.435 \\ 0.378 & 0.582 \end{pmatrix} & \begin{pmatrix} 0.864 & 0.432 \\ 0.337 & 0.603 \end{pmatrix} & \begin{pmatrix} 0.837 & 0.432 \\ 0.280 & 0.458 \end{pmatrix} & \begin{pmatrix} 0.806 & 0.425 \\ 0.238 & 0.418 \end{pmatrix} \\ \begin{pmatrix} 0.864 & 0.432 \\ 0.337 & 0.603 \end{pmatrix} & \begin{pmatrix} 0.837 & 0.432 \\ 0.280 & 0.458 \end{pmatrix} & \begin{pmatrix} 0.806 & 0.425 \\ 0.238 & 0.418 \end{pmatrix} & \begin{pmatrix} 0.779 & 0.421 \\ 0.189 & 0.304 \end{pmatrix} \end{pmatrix}$$

We calculated the following singular values :

| | |
|---|---|
| 4.5333 | 0.0495 |
| 1.2591 | 0.0071 |
| 0.1431 | 0.0018 |
| 0.0729 | 0.0004 |

We computed the ratio of the $i$-th singular value to the first singular value and compared it with the statistic $1/\sqrt{T}$. This lead to set $\hat{n} = 2$.

The coefficients A, G and C can be estimated, as well as the initial condition, by the backcasting technique. These estimates are presented in Table 5.2.

With the initial condition $\hat{x}_0 = \begin{pmatrix} 1.8236 \\ 0.7487 \end{pmatrix}$ we have used the estimated model to obtain in-sample forecasts for the money and output series. Summary statistics of these in-sample forecasts are also reported in Table 5.2.

**TABLE 5.2. ESTIMATION RESULTS FOR MONEY AND OUTPUT**

**Coefficients**

| $\hat{A}$ | | $\hat{G}$ | | $\hat{C}$ | |
|---|---|---|---|---|---|
| 0.9412 | -0.0121 | -0.7655 | -0.3321 | -0.9386 | 0.3245 |
| -0.0916 | 0.8924 | 0.7835 | -1.0041 | -0.6818 | -0.5570 |

**Covariances**

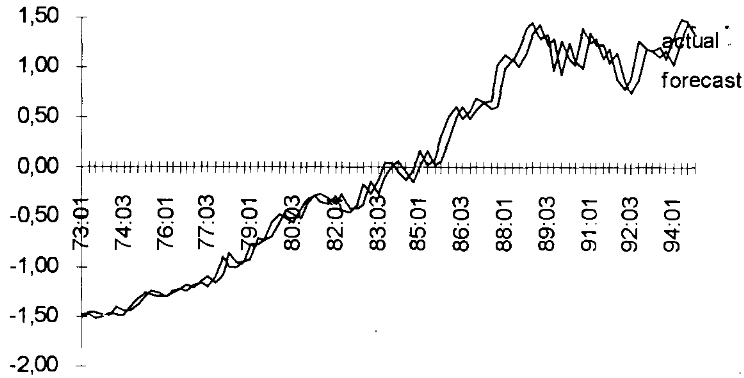
| $\hat{\Pi}$ | | $\hat{\Delta}_e$ | | $\hat{\Delta}_0$ | |
|---|---|---|---|---|---|
| 0.9528 | | 1.0394 | | 0.9886 | |
| 0.0130 | 0.8839 | 0.5186 | 1.1452 | 0.4959 | 0.9886 |

**Summary Statistics**

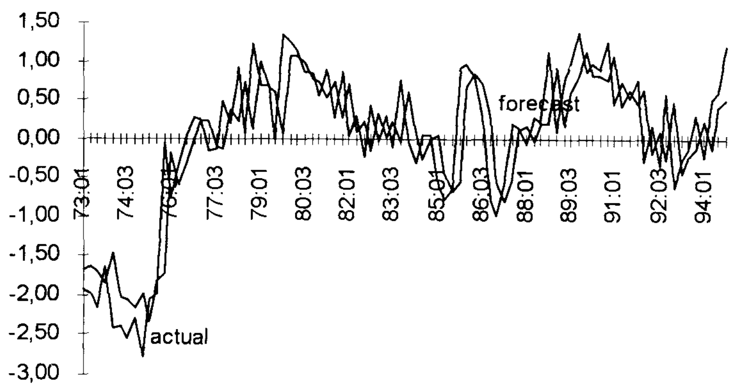
| | Monney | IPI |
|---|---|---|
| AVERAGE | -0.0009 | 0.0078 |
| MAD | 0.1411 | 0.5519 |
| FPE | 0.0199 | 0.3046 |
| RMSE | 0.1069 | 0.4406 |

## TIME PLOTS OF ACTUAL AND IN-SAMPLE FORECAST VALUES

### FIGURE 5.2. MONEY




### FIGURE 5.3. INDEX OF INDUSTRIAL PRODUCTION



## 2.3. THE EXAMPLE OF TRINIDAD AND TOBAGO'S MACROECONOMIC AGGREGATES

The series examined here are the annual macroeconomic aggregates of the GDP demand identity. The $y_t$ vector is then composed of the following variables : national output (GDP), total consumption expenditure (FCE), gross capital formation (GCF), imports of goods and non-factor services (M) and exports of goods and non-factor services (X). The data relate to the period 1970-1994 and correspond to constant prices values at 1987 prices.

Our econometric computations were conducted on the logarithm of the data. We estimated the model after subtracting the means. As we explained previously, the choice of the value for the lag parameters $r$ and $f$ can be a tricky exercise. Here, since we have a short sample of 25 observations of annual data, it seem appropriate to set $r$ and $f$ to one or two. Finally, we choose $r = f = 1$ because with $r = f = 2$ the Hankel matrix will capture information of lag one, two and three, which can lead to large sampling errors.

After this step, the singular value decomposition was applied on a $5 \times 5$ Hankel matrix and has led to the following singular values.

| | | | | | |
|---|---|---|---|---|---|
| $\sigma_i$ | 17.4997 | 2.2926 | 0.2661 | 0.0885 | 0.0000 |

Based on this we choose $\hat{n} = 3$. Table 5.3 summarizes the estimation results, statistics on in-sample forecasts and error autocorrelations.

**TABLE 5.3 : ESTIMATION RESULTS FOR THE VECTOR $(GDP_t \;\; FCE_t \;\; GCF_t \;\; M_t \;\; X_t)'$**

Coefficients

| | $\hat{A}$ | | | | $\hat{G}$ | | | | | $\hat{C}'$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.8274 | -0.1942 | 0.1376 | 0.0030 | -0.2157 | -0.4696 | 0.2464 | -0.4388 | -2.4840 | -2.6764 | -1.2139 | -1.6261 | -0.2199 |
| 0.1779 | 0.9454 | -0.3620 | 0.6450 | -0.5885 | -0.0839 | 0.1158 | -0.8351 | 0.0780 | -0.4849 | 1.2066 | -0.1187 | -0.7624 |
| -0.2624 | 0.0169 | 0.5808 | -0.9990 | 0.9808 | 0.1736 | -0.0624 | -0.4586 | -0.3429 | 0.1454 | -0.0012 | 0.3095 | -0.1776 |

Covariances

| $\hat{\Pi}$ | | | | $\hat{\Delta}_e$ | | | | | | $\hat{\Delta}_0$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9748 | | | 10.467 | | | | | 7.4702 | | | | |
| -0.1717 | 1.0609 | | 9.854 | 10.898 | | | | 7.1764 | 7.7065 | | | |
| 0.1143 | -0.0136 | 0.7954 | 4.620 | 3.947 | 3.848 | | | 4.0536 | 3.2672 | 3.8032 | | |
| | | | 5.492 | 6.062 | 2.386 | 3.826 | | 4.3250 | 4.6337 | 2.3407 | 3.0649 | |
| | | | 1.484 | 1.893 | -0.546 | 0.979 | 1.117 | 0.5652 | 0.8364 | -0.6761 | 0.4154 | 0.8204 |

Summary Statistics

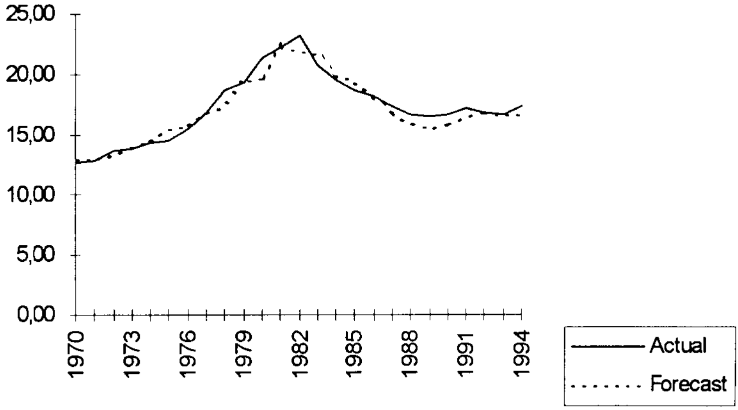
| | GDP | FCE | GCF | M | X |
|---|---|---|---|---|---|
| AVERAGE | 0.0261 | 0.0145 | -0.0131 | -0.0033 | 0.0213 |
| MAD | 0.5213 | 0.5333 | 0.5075 | 0.4436 | 0.3397 |
| FPE | 0.4677 | 0.4689 | 0.4093 | 0.3191 | 0.1655 |
| RMSE | 0.6839 | 0.6847 | 0.6398 | 0.5649 | 0.4068 |

Error autocorrelations, lag 1-4

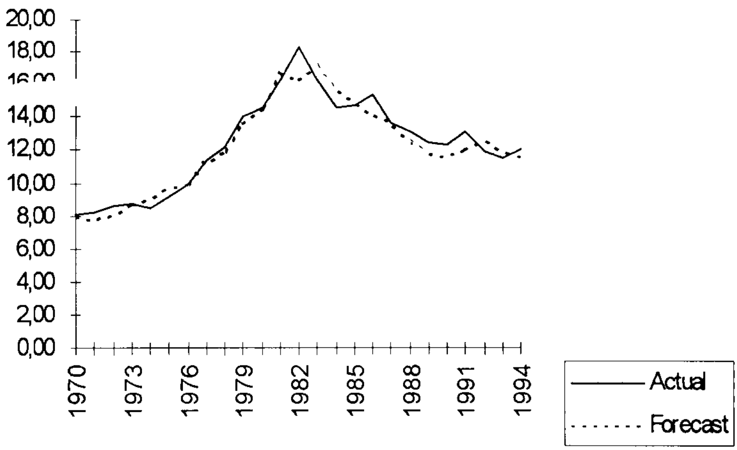
| | lag 1 | lag 2 | lag 3 | lag 4 |
|---|---|---|---|---|
| GDP | 0.0380 | 0.4236 | -0.3727 | 0.0088 |
| FCE | -0.0044 | -0.2839 | -0.0751 | 0.0659 |
| GCF | -0.1087 | 0.1963 | -0.0781 | -0.1020 |
| M | 0.0259 | -0.1545 | -0.0909 | -0.0341 |
| X | 0.2101 | 0.0369 | -0.0230 | 0.0671 |

## TIME PLOTS OF ACTUAL AND IN-SAMPLE FORECAST VALUES

### FIGURE 5.4. GDP

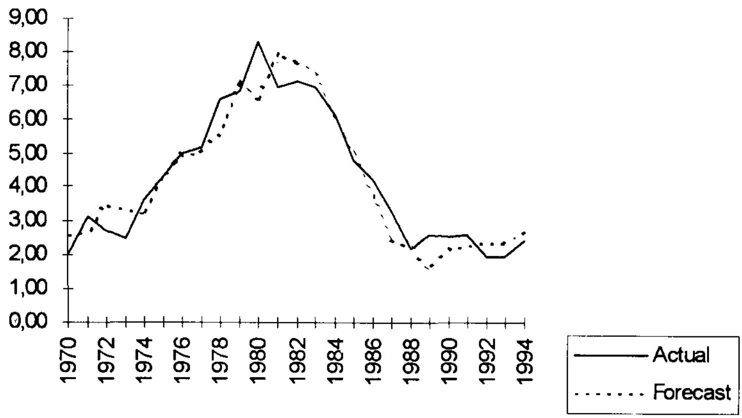



### FIGURE 5.5. CONSUMPTION

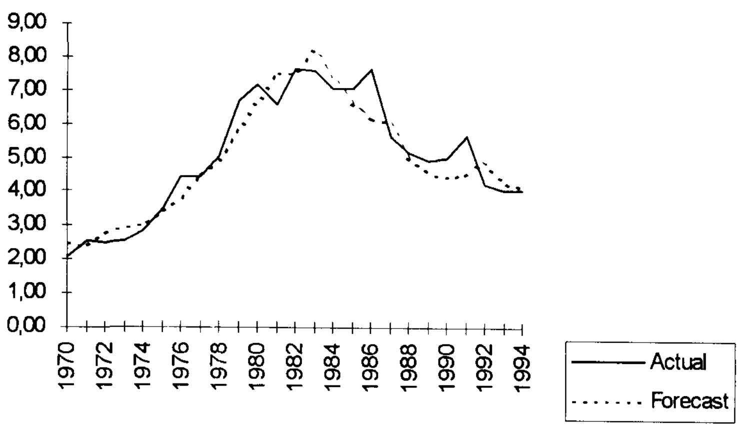


## Time Plots of Actual and in-sample Forecast Values

### Figure 5.6. Gross Capital Formation

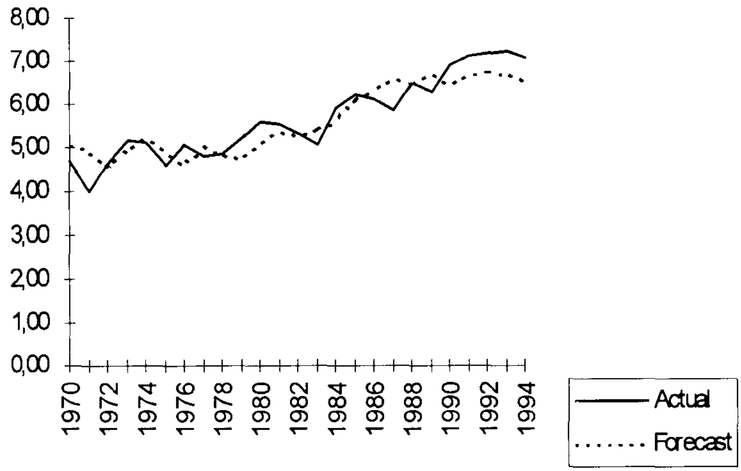



### Figure 5.7. Imports



## TIME PLOTS OF ACTUAL AND IN-SAMPLE FORECAST VALUES

### FIGURE 5.8. EXPORTS




These results indicate that the procedure performs reasonably well. Of course, one notices that the performances are better with less volatile series. In order to draw a parallel with econometric results achievied on similar data, we refer to the cointegrated model by Watson and Teelucksingh (1996) which consists of fifty variables (of which thirty or so are endogenous and twenty are exogenous), from which the ones we use here are taken. It is clear from their graphics profile, that observed data versus forecast data compares well with the profile of graphics obtained with our state space model.

**TABLE 5.4 IN-SAMPLE FORECASTS OF THE 3-STATE MODEL FOR $(GDP_t \quad FCE_t \quad GCF_t \quad M_t \quad X_t)'$**

| GDP | | | | Consumption | | | |
|---|---|---|---|---|---|---|---|
| DATE | ACTUAL | FORECAST | ERRORS AS % OF ACTUAL | DATE | ACTUAL | FORECAST | ERRORS AS % OF ACTUAL |
| 1970 | 12,72 | 13,07 | -2,79 | 1970 | 8,10 | 7,95 | 1,76 |
| 1971 | 12,85 | 13,05 | -1,57 | 1971 | 8,26 | 7,87 | 4,71 |
| 1972 | 13,59 | 13,30 | 2,16 | 1972 | 8,66 | 8,09 | 6,62 |
| 1973 | 13,82 | 14,05 | -1,66 | 1973 | 8,68 | 8,76 | -0,81 |
| 1974 | 14,35 | 14,43 | -0,57 | 1974 | 8,48 | 9,01 | -6,30 |
| 1975 | 14,56 | 15,56 | -6,89 | 1975 | 9,13 | 9,64 | -5,54 |
| 1976 | 15,49 | 15,64 | -0,97 | 1976 | 9,88 | 9,94 | -0,59 |
| 1977 | 16,90 | 16,80 | 0,62 | 1977 | 11,43 | 11,23 | 1,81 |
| 1978 | 18,60 | 17,38 | 6,53 | 1978 | 12,21 | 11,88 | 2,69 |
| 1979 | 19,27 | 19,43 | -0,88 | 1979 | 13,99 | 13,47 | 3,67 |
| 1980 | 21,27 | 19,69 | 7,40 | 1980 | 14,52 | 14,56 | -0,24 |
| 1981 | 22,24 | 22,30 | -0,28 | 1981 | 16,35 | 16,52 | -1,03 |
| 1982 | 23,09 | 21,76 | 5,77 | 1982 | 18,32 | 16,33 | 10,89 |
| 1983 | 20,71 | 21,65 | -4,55 | 1983 | 16,30 | 17,09 | -4,88 |
| 1984 | 19,52 | 19,83 | -1,60 | 1984 | 14,59 | 15,67 | -7,36 |
| 1985 | 18,71 | 19,44 | -3,91 | 1985 | 14,73 | 15,03 | -2,02 |
| 1986 | 18,10 | 18,15 | -0,31 | 1986 | 15,39 | 14,21 | 7,67 |
| 1987 | 17,27 | 16,86 | 2,37 | 1987 | 13,69 | 13,80 | -0,79 |
| 1988 | 16,60 | 16,06 | 3,23 | 1988 | 13,10 | 12,41 | 5,21 |
| 1989 | 16,46 | 15,53 | 5,62 | 1989 | 12,50 | 11,80 | 5,58 |
| 1990 | 16,71 | 15,75 | 5,70 | 1990 | 12,26 | 11,61 | 5,34 |
| 1991 | 17,15 | 16,52 | 3,72 | 1991 | 13,05 | 12,08 | 7,44 |
| 1992 | 16,86 | 16,81 | 0,35 | 1992 | 11,95 | 12,56 | -5,14 |
| 1993 | 16,63 | 16,68 | -0,27 | 1993 | 11,50 | 11,88 | -3,29 |
| 1994 | 17,40 | 16,75 | 3,75 | 1994 | 12,00 | 11,64 | 3,01 |

**TABLE 5.4 IN-SAMPLE FORECASTS OF THE 3-STATE MODEL FOR** $(GDP_t \quad FCE_t \quad GCF_t \quad M_t \quad X_t)'$

| Investment | | | | Exports | | | |
|---|---|---|---|---|---|---|---|
| DATE | ACTUAL | FORECAST | ERRORS AS % OF ACTUAL | DATE | ACTUAL | FORECAST | ERRORS AS % OF ACTUAL |
| 1970 | 1,99 | 2,59 | -29,93 | 1970 | 2,06 | 2,50 | -20,94 |
| 1971 | 3,12 | 2,66 | 14,70 | 1971 | 2,54 | 2,45 | 3,59 |
| 1972 | 2,75 | 3,50 | -27,21 | 1972 | 2,47 | 2,79 | -12,79 |
| 1973 | 2,48 | 3,33 | -34,22 | 1973 | 2,53 | 2,98 | -17,91 |
| 1974 | 3,58 | 3,23 | 9,94 | 1974 | 2,82 | 3,00 | -6,34 |
| 1975 | 4,34 | 4,35 | -0,11 | 1975 | 3,52 | 3,36 | 4,43 |
| 1976 | 4,97 | 4,90 | 1,46 | 1976 | 4,43 | 3,78 | 14,79 |
| 1977 | 5,13 | 5,00 | 2,52 | 1977 | 4,46 | 4,42 | 0,74 |
| 1978 | 6,57 | 5,59 | 14,96 | 1978 | 5,01 | 4,93 | 1,75 |
| 1979 | 6,78 | 7,03 | -3,62 | 1979 | 6,69 | 5,82 | 12,95 |
| 1980 | 8,31 | 6,59 | 20,74 | 1980 | 7,17 | 6,57 | 8,31 |
| 1981 | 6,93 | 7,94 | -14,64 | 1981 | 6,55 | 7,51 | -14,59 |
| 1982 | 7,11 | 7,71 | -8,44 | 1982 | 7,65 | 7,54 | 1,49 |
| 1983 | 6,90 | 7,28 | -5,51 | 1983 | 7,56 | 8,17 | -8,09 |
| 1984 | 6,12 | 5,92 | 3,29 | 1984 | 7,07 | 7,34 | -3,76 |
| 1985 | 4,79 | 4,96 | -3,54 | 1985 | 7,02 | 6,64 | 5,47 |
| 1986 | 4,19 | 3,76 | 10,32 | 1986 | 7,61 | 6,15 | 19,23 |
| 1987 | 3,34 | 2,48 | 25,63 | 1987 | 5,61 | 6,02 | -7,29 |
| 1988 | 2,20 | 2,25 | -2,18 | 1988 | 5,16 | 5,06 | 1,95 |
| 1989 | 2,61 | 1,57 | 39,75 | 1989 | 4,89 | 4,54 | 7,14 |
| 1990 | 2,53 | 2,19 | 13,45 | 1990 | 4,98 | 4,44 | 10,94 |
| 1991 | 2,63 | 2,29 | 13,08 | 1991 | 5,61 | 4,52 | 19,35 |
| 1992 | 1,98 | 2,34 | -18,37 | 1992 | 4,23 | 4,85 | -14,49 |
| 1993 | 1,97 | 2,38 | -20,67 | 1993 | 4,04 | 4,28 | -6,07 |
| 1994 | 2,41 | 2,73 | -13,57 | 1994 | 4,05 | 4,14 | -2,05 |

**TABLE 5.4. IN-SAMPLE FORECASTS OF THE 3-STATE MODEL FOR $(GDP_t\ \ FCE_t\ \ GCF_t\ \ M_t\ \ X_t)'$ -CONCLUDED**

Imports

| DATE | ACTUAL | FORECAST | ERRORS AS % OF ACTUAL |
|---|---|---|---|
| 1970 | 4,70 | 5,03 | -7,09 |
| 1971 | 4,01 | 4,97 | -23,90 |
| 1972 | 4,66 | 4,50 | 3,28 |
| 1973 | 5,18 | 4,95 | 4,56 |
| 1974 | 5,10 | 5,19 | -1,63 |
| 1975 | 4,60 | 4,93 | -7,31 |
| 1976 | 5,07 | 4,58 | 9,68 |
| 1977 | 4,80 | 4,99 | -4,15 |
| 1978 | 4,83 | 4,84 | -0,20 |
| 1979 | 5,19 | 4,76 | 8,28 |
| 1980 | 5,60 | 5,12 | 8,60 |
| 1981 | 5,51 | 5,35 | 2,99 |
| 1982 | 5,30 | 5,25 | 0,98 |
| 1983 | 5,07 | 5,45 | -7,47 |
| 1984 | 5,87 | 5,58 | 5,00 |
| 1985 | 6,21 | 6,09 | 1,91 |
| 1986 | 6,13 | 6,33 | -3,34 |
| 1987 | 5,85 | 6,60 | -12,74 |
| 1988 | 6,46 | 6,45 | 0,03 |
| 1989 | 6,24 | 6,70 | -7,36 |
| 1990 | 6,90 | 6,40 | 7,27 |
| 1991 | 7,08 | 6,67 | 5,77 |
| 1992 | 7,17 | 6,75 | 5,90 |
| 1993 | 7,20 | 6,70 | 6,88 |
| 1994 | 7,04 | 6,51 | 7,58 |

## Conclusion

For the past fifteen years or so, economists have sought models and concepts to describe, as best as they could, the evolution of economic variables. In an effort to address the deficiencies of traditional macroeconometric models, this research has used a tool which can considerably enrich and renew econometric analysis (causality, non stationarity, cointegration, seasonality and non linearity). The object of this article is to present the state space modelling approach as a means to this end and also to try to demonstrate that this approach constitutes a satisfactory alternative to other forecasting methods.

We took a special interest in the computer implementation, making sure that the algorithms that we chose were noted for their precision. The illustrations that we used have thus shown that state space models provide good results. In the context of Caribbean countries, this study allowed us to show that the state space models can be a very interesting forecasting tool.

Broadly speaking, considering their low estimation cost and their great flexibility to model data of various types, we think that these models could definitely find a place in the "toolbox" of any institution or individual engaged in forecasting in the Caribbean.

## Notes

1. Université des Antilles et de la Guyane et LEAD (Laboratoire d' Appliquée au Développement).

2. The innovation form stands out by the presence of the same innovations in the state equation and the observation equation. The choice of this model does not lose generality because the passage to the classical model is done by a spectral factorization of the matrixes $(A,G,C)$.

3. In the systems theory, the model (4) is said stable if and only if, for a positive matrix $Q$, there is a positive matrix $P$, unique solution of the Lyapunov equation $A'PA-P=-Q$.

4. AVERAGE is the average error, MAD is the mean absolute deviation error, FPE is the final prediction error, and RMSE is the root mean squared error.

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# CHAPTER

# 6

# PURCHASING POWER PARITY (PPP) IN THE CARICOM REGION, 1973-1995

*Anston Rambarran*

# Purchasing Power Parity (PPP) in the CARICOM Region, 1973-1995

*Anston Rambarran*

*The author is an Economist in the Research Department of the Central Bank of Trinidad and Tobago. The views expressed are those of the author and not necessarily those of the Central Bank.*

## I. Introduction

Purchasing power parity (PPP) is undoubtedly one of the older and more controversial of hypotheses in international finance. Elements of the doctrine date to the sixteenth century, although its modern concept is intrinsically linked to the works of Cassel in the unsettled monetary aftermath of the 1920s.[1] An absolute or strong version of PPP states that the exchange rate equals the ratio of domestic to foreign prices, while a relative or weak version states that the change in the exchange rate is equal to the inflation differential. The controversy associated with the hypothesis arose therefore because it specified a relationship between exchange rates and prices but not an adjustment mechanism. As a result, a multiplicity of interpretations and a lack of professional consensus characterized the early literature on whether PPP is a theory of exchange rate determination or simply an equilibrium relationship.

The collapse of the Bretton Woods system of fixed exchange rates in 1973 and the move towards generalized floating by the industrialized countries witnessed a resurgence of attention in PPP.

The doctrine became fundamental to modern theoretical models of exchange rate determination and PPP-oriented exchange rate rules were used to predict exchange rate movements. Several studies including Artus (1978), Officer (1976,1980), Frenkel (1981), Hakkio (1982), and Rush and Husted (1985) investigated the validity of PPP in the post Bretton Woods era and all reached different conclusions. It is now recognized that a basic flaw in all these studies was the failure to consider the possible nonstationarity of exchange rates and relative prices, which made invalid the standard hypothesis tests performed (Froot and Rogoff, 1994).

Recent innovations in econometric techniques and the development of longer data sets are now contributing to a new wave of research on PPP. Of particular interest are the studies that use cointegration techniques, which abstract from short-run dynamics and test for long-run equilibrium relationships where the adjustment mechanism remains unspecified.[2] The consensus arising from these studies is that the industrialized countries appear to exhibit long-run convergence to PPP, while in the less-developed countries (LDCs) the case remains inconclusive given the dearth of empirical work on PPP. There is thus considerable scope as well as avenues for increased comparability in expanding the research on PPP to include the developing countries, even though the prevalence of fixed exchange rate systems appears to negate such a prospect. Bahmani-Oskooee (1993) argues, however, that it is the concept of the effective exchange rate that is relevant to developing countries in testing for PPP. This is because LDCs are generally unable to avoid fluctuations in their effective exchange rates despite pegging to a major currency or to a basket of currencies that float against each other.

Indeed, this proposition is supported by Bennett (1988) who argues that countries within CARICOM have effectively been operating under an indirect managed floating exchange rate regime since 1973, as their currencies are anchored to the US dollar which is floating against the currencies of all the major industrial countries. Furthermore, even though the United States remains the major trading partner in CARICOM, a significant share of trade is conducted with other countries both regionally and extra-regionally. As a result, even with unchanged bilateral US exchange rates, the stability of effective exchange rates in the CARICOM region to a large extent depends on the level of the US dollar relative to that of other major international currencies. Moreover, the possible existence of PPP would serve to strengthen the institutional framework for managing intra-CARICOM exchange rates in the quest for regional economic integration (Bandawe and Glen, 1991).

Although CARICOM consists of thirteen countries, this study is concerned with eleven member states due to the availability of data. Exchange rate arrangements in these member states lie at either end of the spectrum. Barbados and the seven countries of the Organisation of Eastern Caribbean States (OECS) maintain fixed parities with the US dollar, albeit at levels unchanged since the delinking from the pound sterling in the 1970s.[3] Furthermore, the OECS countries maintain a monetary union under the auspices of the Eastern Caribbean Central Bank (ECCB) with a single currency functioning as legal tender. In contrast, the three countries of Jamaica, Guyana and Trinidad and Tobago have moved toward greater exchange rate flexibility as part of their structural adjustment efforts. Jamaica introduced a flexible exchange rate system in September 1990, after experimenting with various exchange rate arrangements in the late 1970s. Guyana also explored several changes to its fixed parity before allowing the rate to be largely determined by market forces in September 1991, while Trinidad and Tobago introduced a managed floating exchange rate system in April 1993. Despite this dichotomy in exchange rate arrangements, inevitably there are common modalities in exchange rate management as espoused by Bennett (1988).

Accordingly, this study is an attempt to investigate the empirical validity of PPP for these eleven Caribbean countries over the period 1973-1995. The analysis uses low frequency (annual) data[4] based on the concepts of the effective exchange rate and the effective price level. The paper is organized as follows. Section II describes the analytical framework, while Section III reports on some useful summary statistics and examines whether nominal effective exchange rates and effective price levels are cointegrated using the Johansen test. Policy implications and concluding remarks are made in Section IV.

## II. The Analytical Framework

The methodological framework follows that of Officer (1980) which refers to PPP in its relative form and the exchange rate and price levels are redefined as index number ratios of current period to base period values. Let $r_t$ denote the exchange rate (number of units of domestic currency per unit of foreign currency) in period t, and let $p_t$ and $p_t^*$ be the domestic and foreign price index in period t relative to the base period 0, respectively. Then, the exchange rate index $R_n$ and the relative price index $P_n$ in the current period n are defined as $R_n = r_n / r_0$ and $P_n = p_n / p_n^*$, respectively.

This computation provides the basis for testing the comparative static approach to PPP; the closer $R_n$ is to $P_n$, the stronger the predictive power of the hypothesis. Other elements of the framework include choosing an appropriate price index, standard country, base and current periods, and sample of domestic countries. The gross domestic product (GDP) deflator is selected as the price measure in this study because it is the only price concept with a strong foundation in PPP theory. In contrast, other studies have used the consumer price index (CPI) or wholesale price index (WPI), even though the latter is biased in favour of the theory because it is heavily weighted with traded goods. For the countries in CARICOM, the standard country is the United States while for a given domestic country, the optimal standard country is the one with which trade and payments links are strongest. This suggests the use of the effective exchange rate, which replaces the standard country's currency and price index with appropriately weighted averages of the currencies and price indices of the domestic country's major trading partners.

In this regard, the definition and method of construction of the nominal effective exchange rate (NEER) and the effective price (EP) index builds on previous notation as follows. Let

$NEER_{in}$ = the nominal effective exchange rate for currency *i* in period *n* relative to period *0*, number of units of domestic currency per unit of foreign currency.

$R_{ijn}$ = exchange rate index between currency *i* and currency *j* in period *n* relative to period *0*, number of units of currency *i* per unit of currency *j*.

$w_{ij}$ = weight of currency $j$ in the effective exchange rate index for currency $i$.

Then, by definition,

$$NEER_{in} = \Pi_j R_{ijn}^{w_{ij}}, \tag{1}$$

where $w_{ij} = 1$ and $w_{ii} = 0$. Officer (1980) indicates that a geometric weighted average index should be used because it is subject to the properties of symmetry (interchangeability of currencies $i$ and $j$), and reversibility (interchangeability of periods 0, and $n$). Assuming orderly cross rates involving the US dollar (denoted by subscript \$), then

$$NEER_{in} = \Pi_j \left(R_{i\$n}/R_{j\$n}\right)^{w_{ij}}, \tag{2}$$

Thus, the NEER can be calculated from exchange rate data with the US dollar as the base currency. The effective price index EP is similarly defined. Let,

$EP_{in}$ = the effective price index for country i in period $n$ relative to period *0*, domestic price index divided by the foreign price index.

$P_{kn}$ = price index of country $k$ in period $n$ relative to period *0*.

Then,

$$EP_{in} = \Pi_i \left(P_{in}/P_{jn}\right)^{W_{ij}}, \tag{3}$$

The major trading partners for each of the eleven countries include their ten regional partners and the following six developed countries: Canada, Germany, Japan, the Netherlands, the United Kingdom and the United States. The weight $w_{ij}$ is proportional to the value of merchandise trade (exports plus imports) of country *i* with country *j*. In the computations the base and current periods play equal roles in determining the weights. An intervening period between base and current period is also used. An intervening period (say, period m) is similar to the current period in the sense that $NEER_{im}$ and $EP_{im}$ can be calculated. Moreover, the weights can then be re-calculated using the trade flows in period *m* in conjunction with the flows in period *0*. This procedure has the advantage that the series can be linked using the intervening period, thereby incorporating any structural changes in the direction of trade. In the study, 1982 is used as the intervening period to which the linked series is then rebased, that is, 1982=100.

Table 6.1 describes the weighting pattern of the NEER and EP indices corresponding to the respective period for each country in the sample. The coverage of the indices refers to the proportion of total trade accounted for by the main trading partners and is listed in the final column of Table 6.1. Annual data on exchange rates and gross domestic product (GDP) over the period 1973 to 1995 were obtained from the IMF's *International Financial Statistics Yearbook,* and the direction of trade weights were calculated from the IMF and IBRD's *Direction of Trade Statistics Yearbook.*

TABLE 6.1
WEIGHTING PATTERNS FOR
NOMINAL EFFECTIVE EXCHANGE RATES

| Country | Period | Weighting Pattern | Coverage (%) |
|---|---|---|---|
| Trinidad & Tobago | 1973-1982 | 0.54 US + 0.176 UK + 0.07 CAN + 0.16 GER + 0.037 JAP + 0.086 NET + 0.032 GUY + 0.019 JAM + 0.018 BAR + 0.006 OECS | 86.3 |
| | 1982-1995 | 0.66 US + 0.076 UK + 0.043 CAN + 0.017 GER + 0.038 JAP + 0.047 NET + 0.029 GUY + 0.027 JAM + 0.032 BAR + 0.009 OECS | 74.1 |
| Barbados | 1973-1982 | 0.357 US + 0.304 UK + 0.098 CAN + 0.02 GER + 0.022 JAP + 0.014 NET + 0.016 GUY + 0.117 TT + 0.014 JAM + 0.038 OECS | 73.6 |
| | 1982-1995 | 0.448 US + 0.16 UK + 0.059 CAN + 0.03 GER + 0.031 JAP + 0.01 NET + 0.011 GUY + 0.189 TT + 0.015 JAM + 0.047 OECS | 67.6 |
| Guyana | 1973-1982 | 0.28 US + 0.268 UK + 0.12 CAN + 0.034 GER + 0.032 JAP + 0.026 NET + 0.204 TT + 0.018 JAM + 0.01 BAR + 0.008 OECS | 88.7 |
| | 1982-1995 | 0.346 US + 0.233 UK + 0.074 CAN + 0.036 GER + 0.056 JAP + 0.024 NET + 0.192 TT + 0.016 JAM + 0.011 BAR + 0.012 OECS | 84.9 |
| Jamaica | 1973-1982 | 0.521 US + 0.186 UK + 0.143 CAN + 0.03 GER + 0.029 JAP + 0.025 NET + 0.007 GUY + 0.043 TT + 0.008 BAR + 0.008 OECS | 68.9 |
| | 1982-1995 | 0.581 US + 0.144 UK + 0.093 CAN + 0.025 GER + 0.039 JAP + 0.036 NET + 0.005 GUY + 0.052 TT + 0.012 BAR + 0.013 OECS | 72.4 |

**TABLE 6.1 - CONT'D
WEIGHTING PATTERNS FOR
NOMINAL EFFECTIVE EXCHANGE RATES**

| Country | Period | Weighting Pattern | Coverage (%) |
|---|---|---|---|
| OECS | 1973-1982 | 0.315 US + 0.427 UK + 0.84 CAN + 0.003 GER + 0.016 JAP + 0.017 NET + 0.008 GUY + 0.067 TT + 0.017 JAM + 0.046 BAR | 87.4 |
| | 1982-1995 | 0.397 US + 0.28 UK + 0.053 CAN + 0.041 GER + 0.042 JAP + 0.008 NET + 0.009 GUY + 0.105 TT + 0.028 JAM + 0.037 BAR | 81.5 |

Sources: Calculated from IMF - **International Financial Statistics Yearbook** (various issues), and IMF and IBRD - **Direction of Trade Statistics Yearbook** (various issues).

Notes: The same weighting patterns are used for the corresponding effective price indices. Obvious symbols are used to represent component countries in the effective exchange rate. Coverage refers to trade with countries included in the weighting pattern as a proportion of the domestic country's total trade.

## III. Testing for PPP in the Short and Long Run

Define the logarithm of the nominal effective exchange rate index as $e$, and the logarithm of the effective price index as $\pi$, then the absolute or strong version of PPP implies that the logarithm of the real effective exchange rate index $q$ be zero. That is,

$$q_t = e_t - \pi_t = 0, \tag{4}$$

The relative or weak version of PPP is equation (4) in first differences, that is,

$$\Delta q_t = \Delta e_t - \Delta \pi_t = 0, \tag{5}$$

Table 6.2A reports the cross-correlations of the logarithms of nominal effective exchange rate changes and effective inflation rates estimated from 3 leads to 3 lags. These calculations reveal that changes in both the exchange rate and price level are largely uncorrelated at these leads and lags. Similarly, contemporaneous movements in nominal effective exchange rates and effective inflation rates appear to be uncorrelated, with the sample correlations ranging from -0.9095 for the US - Guyana pair to 0.1481 for the US - OECS pair. Table 6.2B displays sample cross-correlations between changes in real and nominal effective exchange rates from 3 leads to 3 lags. Generally, the contemporaneous movements in real and nominal effective exchange rates are positively correlated for each of the five currencies, while correlations at non-zero leads and lags are basically close to zero. Table 6.2C shows the sample standard deviations of effective inflation differentials and changes in the logarithms of nominal and real effective exchange rates. The statistics seem to suggest that real rates are significantly more variable than nominal rates, and changes in the nominal effective exchange rate vary in tandem with changes in the effective price level.

**TABLE 6.2A.**
**CROSS-CORRELATIONS OF CHANGES IN LOGARITHMS OF NOMINAL EFFECTIVE EXCHANGE RATES AND EFFECTIVE INFLATION RATES, 1973-1995:**

**Corr ($\Delta e_t$, $\Delta q(t-k)$)**

**k = lag of prices relative to exchange rate**

| Country | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|
| Trinidad | 0.0250 | 0.0691 | 0.2223 | 0.0850 | -0.0363 | 0.1406 | 0.0145 |
| Barbados | 0.1239 | 0.3571 | 0.2548 | -0.1737 | -0.2644 | -0.5480 | -0.0806 |
| Guyana | -0.0738 | -0.4805 | -0.3044 | -0.9095 | -0.2456 | -0.5926 | -0.0389 |
| Jamaica | 0.5015 | -0.0307 | 0.1614 | -0.1119 | 0.0543 | 0.0774 | 0.1933 |
| OECS | -0.0326 | 0.2099 | 0.0984 | 0.1481 | -0.0336 | 0.2843 | 0.3675 |

**TABLE 6.2B**
**CROSS-CORRELATIONS OF CHANGES IN LOGARITHMS OF NOMINAL EFFECTIVE EXCHANGE RATES AND REAL EFFECTIVE EXCHANGE RATES, 1973-1995:**

**Corr $(\Delta e_t, \Delta q_{(t-k)})$**

**k = lag of real effective exchange rate to nominal effective exchange rate**

| Country | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|
| Trinidad | -0.0491 | -0.1001 | -0.2221 | 0.7493 | -0.0566 | -0.1217 | -0.0409 |
| Barbados | -0.2538 | -0.3249 | -0.1301 | 0.6602 | 0.2649 | 0.4231 | -0.0560 |
| Guyana | 0.0513 | 0:5116 | 0.1968 | 0.9819 | 0.1697 | 0.5615 | 0.0344 |
| Jamaica | -0.5156 | -0.2078 | 0.2446 | 0.9157 | 0.2805 | -0.2529 | -0.4939 |
| OECS | -0.0982 | -0.1914 | 0.0260 | 0.5404 | 0.1652 | -0.02452 | -0.3999 |

**TABLE 6.2C**
**SAMPLE STANDARD DEVIATIONS OF INFLATION DIFFERENTIALS AND CHANGES IN LOGARITHMS OF NOMINAL AND REAL EFFECTIVE EXCHANGE RATES, 1973-1995**

| Country | Inflation Differential | Change in Logarithm of Nominal Effective Exchange Rate | Change in Logarithm of Real Effective Exchange Rate |
|---|---|---|---|
| Trinidad | 0.0893 | 0.1083 | 0.1344 |
| Barbados | 0.0706 | 0.0372 | 0.0539 |
| Guyana | 0.2778 | 0.3462 | 0.6099 |
| Jamaica | 0.1087 | 0.2340 | 0.2688 |
| OECS | 0.0500 | 0.0391 | 0.0588 |

These summary statistics suggest that PPP breaks down in the short-run for the sample of five Caribbean currencies and it may be reasonable to approximate real effective exchange rates as a martingale, a stochastic process in which successive increments are unpredictable. In light of the relative low variability of inflation differentials, changes in real effective exchange rates appear in the main to be dominated by movements in nominal effective exchange rates. Abstracting from the short-run evidence, however, there could be some sense in which PPP might fare better in the long run when there is a tendency for the real effective exchange rate to revert to parity. The economic rationale for such an inference begins with say a monetary shock that causes the real effective exchange rate to deviate from equilibrium. Since PPP does not hold in the short-run, these deviations persist and cumulate. Economic forces in the form of international commodity arbitrage and the price-specie-flow mechanism then create a countervailing tendency for the real effective exchange rate to return to parity, though possibly after long and variable lags. In this regard, the empirical validity of long-run PPP in the Caribbean region is now examined by using the Johansen test for cointegration.[5]

Table 6.3 reports Dickey-Fuller tests for unit roots on the series over the sample period. For the five currencies considered the logarithm of the nominal effective exchange rate and the logarithm of the effective price level appear uniformly to be non-stationary in levels and stationary in first differences. Based on the evidence, each series is characterized as integrated of order one.

The Johansen maximum likelihood procedure (trended case) is applied to the variables with a maximum of four lags in the VAR. Table 6.4 displays the values of the Johansen maximal eigenvalue

TABLE 6.3
UNIT ROOT TEST RESULTS

| | Trinidad | | Barbados | | Guyana | | Jamaica | | OECS | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variable | DF | ADF(1) | DF | ADF(1) | DF | AFD(1) | DF | ADF(1) | DF | ADF(1) |
| $e_t$ | 1.73 | 1.68 | 0.95 | 0.73 | 1.81 | 3.82 | 3.23 | 5.35 | 1.60 | 2.47 |
| $\Delta e_t$ | 2.14 | 3.89* | 1.81 | 4.42* | 4.33 | 3.75* | 3.80 | 4.15* | 3.40 | 4.70* |
| $\pi_t$ | 0.59 | 2.33 | 0.68 | 1.i1 | 1.55 | 1.54 | 1.25 | 2.13 | 0.43 | 1.54 |
| $\Delta\pi_t$ | 0.57 | 4.60* | 3.63 | 3.77* | 0.33 | 4.35* | 0.45 | 3.92* | 2.48 | 3.931* |

**Notes:** All equations are estimated with a constant term and one lagged value of the dependent variable. At the 5 per cent level of significance, values taken from Fuller (1976, Table 8.5.2) are 3.6592 for DF levels, 3.6746 for ADF levels and 3.6921 for ADF differences. An asterisk denotes significance at the 5 per cent level.

test statistic for at most r linearly independent vectors in the trivariate model $X_t = \left(e_t, p_t, p_t^*\right)'$, where $p_t$ and $p_t^*$ represent the logarithm of the domestic price level and the foreign price level, respectively. Significant evidence of cointegration is found with the results generally supportive of the long-run PPP relationship.

**TABLE 6.4**
**RESULTS OF THE JOHANSEN TEST FOR COINTEGRATION IN THE TRIVARIATE MODEL**

| | n=3 | | |
|---|---|---|---|
| **Country** | **Ho: r ≤ 2** | **r ≤ 1** | **r = o** |
| Trinidad | 1.66 | 15.08* | 35.84* |
| Barbados | 0.63 | 19.93* | 57.45* |
| Guyana | 10.75 | 37.27* | 53.39* |
| Jamaica | 7.26* | 8.69 | 30.99* |
| OECS | 14.07* | 32.00* | 78.64* |

**Note:** Critical values for the likelihood ratio statistic - 2 ln $Q_r$ ($0 \leq r \leq n$) are based on the simulated values tabulated in Johansen and Juselius (1990, table A.2, p. 208). At the 5 per cent level of significance, the critical values are as follows: for n-r=1, 3.7620; for n-r=2, 14.0690; and for n-r=3, 20.9670. An asterisk denotes significance at the 5 per cent level.

For all five currencies the hypothesis of no cointegrating vector (r = 0) can be rejected at the 5 per cent level of significance, indicating that the series in $X_t$ is cointegrated. Further, in four out of five cases (Trinidad, Barbados, Guyana and the OECS) the hypothesis of at most one cointegrating vector $(r \leq 1)$ was rejected, and in two out of five cases (Jamaica and the OECS) the hypothesis of at most two cointegrating vectors $(r \leq 2)$ was rejected.

To illustrate the possible differences in test results among the trivariate, bivariate, and univariate models, Johansen tests were conducted on the bivariate model with nominal effective exchange rates and effective price levels $X_t = \left(e_t, p_t - p_t^*\right)'$, and the univariate model of the real effective exchange rate $X_t = \left(e_t - p_t + p_t^*\right)'$. Table 6.5 shows that the results are not as favourable when compared to the trivariate model. For the bivariate model, the hypothesis of no cointegrating vector was rejected in all five cases at the 5 per cent level of significance, but the hypothesis of at most one cointegrating vector could not be rejected. The results for the univariate model demonstrate only one case (Guyana) supportive of cointegration. In effect, the imposition of symmetry and proportionality restrictions which leads to a bivariate or univariate model suggests that caution be exercised when interpreting these results. According to Cheung and Lai (1993) the imposition of such restrictions may bias the test towards finding no cointegration, which may be interpreted as rejection of the imposed restrictions on the equilibrium condition rather than rejection of the equilibrium relationship.

**TABLE 6.5**
**RESULTS OF THE JOHANSEN TEST FOR COINTEGRATION IN THE BIVARIATE AND UNIVARIATE MODELS**

| | n=2 | | n=1 |
|---|---|---|---|
| **Country** | **Ho: $r \leq 1$** | **r=0** | **r=0** |
| Trinidad | 0.02 | 6.12* | 0.00 |
| Barbados | 0.37 | 8.07* | 0.81 |
| Guyana | 0.52 | 40.32* | 21.94* |
| Jamaica | 1.38 | 12.77* | 1.04 |
| OECS | 0.22 | 26.50* | 3.34 |

**Note:** Critical values for the likelihood ratio statistic -21 $Q_r$ $(0 \leq r \leq n)$ are based on the simulated values tabulated in Johansen and Juselius (1990, Table A.2, p.208). At the 5 per cent level of significance, the critical values are as follows: for n-r=1, 3.7620; for n-r=2, 14.0690. An asterisk denotes significance at the 5% level.

## IV. CONCLUDING REMARKS

This study attempts to investigate the empirical validity of purchasing power parity (PPP) for the currencies of Barbados, Guyana, Jamaica, the OECS, and Trinidad and Tobago during the period 1973-1995. The analysis is based on the concepts of the nominal effective exchange rate and effective price level. The results from the Johansen test for cointegration of the trivariate model (nominal effective exchange rate, domestic price level, foreign price level) are generally supportive of the long-run PPP relationship. Results from the bivariate (nominal effective exchange rates and effective price levels) and univariate (real effective exchange rate) models are not as favourable. In the case of the bivariate model, the hypothesis of no cointegrating vector was rejected in all five cases at the 5 per cent level of significance, but the hypothesis of at most one cointegrating vector could not be rejected. The univariate model demonstrated only one case (Guyana) supportive of cointegration.

Additionally, these findings can be compared with those of Bahmani- Oskooee (1993) who tested the absolute version of PPP using the concept of the effective exchange rate for 25 LDCs over 1973-1988. Even though that study concluded that the test of PPP had failed in both low-inflation and high-inflation LDCs, there was evidence of cointegration in 7 out of 16 countries when PPP was tested using bilateral exchange rates.

Some caution should nonetheless be exercised in the interpretation of these results. One such caveat arises from changes in the exchange rate regime. As documented by Stockman (1983) and Mussa (1986), the behaviour of nominal and real exchange rates differ significantly across periods of fixed and flexible exchange rate regimes. This is particularly relevant when considering the results of the three countries that switched to floating exchange rate systems. Another caveat is that the 'true' long-run may inevitably be longer than the 23 years of data exploited in the study. In this regard, the sample would effectively represent less than one observation on long-run behaviour, with a higher probability of committing Type I errors.

This notwithstanding, the macroeconomic policy implications of the validity of long-run PPP for the Caribbean region are quite salient. For countries operating under fixed exchange rate regimes (Barbados and the OECS), the results imply that in the long run the level of domestic prices is effectively determined by the foreign price level. As a consequence, the efficacy of domestic monetary and fiscal policies in terms of maintaining price stability is weakened, except to the extent that these policies can influence the international price level in some significant manner. For the three countries operating under flexible exchange rate regimes (Guyana, Trinidad and Tobago, Jamaica), the domestic price level is in the long run determined by the home country as the exchange rate moves to ensure PPP. There is therefore some degree of autonomy in using monetary and fiscal policies to achieve price stability.

Moreover, the possible existence of a long-run equilibrium relationship between changes in the nominal effective exchange rate and the effective rate of inflation implies that PPP-oriented exchange rate rules may have some institutional relevance in stabilizing intra-CARICOM exchange rates. This is particularly important in light of the active consideration being given to the formation of a Caribbean monetary union that requires convergence of economic performance and policy. From this perspective, Heliwell (1979) argues that the strict application of PPP entails no policy or welfare significance for the exchange rate since exchange rate risk is the outcome of relative and general price level variability. Of course, from a practical viewpoint the matrix of policy options remains.

In conclusion, it is evident that PPP is not sufficient as an explanation of exchange rate determination in CARICOM member countries. Other factors that underscore the complexity of the issue need to be addressed, including uncovered interest parity, the existence of a risk premium, the role of news, the treatment of expectations and the linkages between the goods and asset markets. Meanwhile, the controversy surrounding PPP continues.

## Notes

1 See Officer (1976) and Dornbusch (1987) for excellent historical reviews of purchasing power parity (PPP).

2 Studies that test whether nominal exchange rates and price levels are cointegrated include Huizinga (1987), Taylor (1988), Mark (1990), Fisher and Park (1991), and Cheung and Lai (1993). Several studies have also attempted to analyse the impact of such fundamental factors as productivity, government expenditure and strategic pricing decisions of firms on real exchange rates.

3 The seven countries of the Organisation of Eastern Caribbean States (OECS) are Antigua, Dominica, Grenada, Montserrat, St. Kitts/Nevis, St. Lucia and St. Vincent.

4 Frankel (1986) argues that the validity of long-run PPP is most accurately tested using annual data over an extended period, while Hendry (1986) states that simply increasing the sample size by temporal disaggregation, say, from years to months, is unlikely to reveal any long-run relationship.

5 Results using the traditional Engle-Granger approach revealed little evidence of cointegration between nominal effective exchange rates and effective price levels for all five currencies. However, these results could not be offered as conclusive proof that the real effective exchange rate has a unit root, especially given the low power advantage of the standard residual based tests compared to the Johansen test.

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