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Money, income and causality: An open economy reexamination

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Money, income and causality: An open economy reexamination

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MONEY, INCOME AND CAUSALITY: AN OPEN ECONOMY REEXAMINATION

BY

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DISSERTATION

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in

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This dissertation has been examined and approved.

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DEDICATION

I dedicate this dissertation to the memory of my father.

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A number of individuals contributed to the completion of this dissertation. I would like to extend special thanks to the members of my committee: Professor Evangelos O. Simos, Professor Kenneth J. Rothwell, Professor Marvin J. Karson, Professor Richard L. Mills, and Professor Jeffrey E. Sohl. Their encouragement and insightful comments and suggestions have been most helpful and are greatly appreciated.

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ABSTRACT

MONEY, INCOME AND CAUSALITY: AN OPEN ECONOMY REEXAMINATION

by

El-Hachemi Aliouche

University of New Hampshire, May, 1992

The positive relationship between the rate of growth of the money supply and the rate of growth of aggregate income is a widely accepted principle in macroeconomics. However, the direction of the causality between these two variables has been an enduring subject of controversy.

Recent developments in time series analysis, particularly those relating to the concepts of integration and cointegration, and the stationary nature of economic time series, promise to help settle the debate on the statistical relationship between money supply growth and income growth. Most of the recent work on this issue, however, has been confined to a closed economy framework and has dealt only with US data. This dissertation extends the scope of the recent work on money-income causality to an open economy framework. Three distinctly different economies are investigated: the United States (large economy), Canada (smaller, fairly open economy), and the Netherlands (small, very open economy). The impact of two international variables (world money supply and world aggregate income) on the direction of causality between domestic money supply and domestic income are explicitly examined, using monthly data over the period 1960-1990 and optimally selected lags for the model specifications. Money-income causality is tested over the full sample (1960-1990), and over sample periods corresponding to alternative exchange rate regimes.

For all three economies, the exchange rate regime is found to be a critical factor in the direction of the causality between domestic money supply and domestic income. In most cases, however, the two international variables (world money supply and world income) do not appear to have a significant impact on the direction of the causality. The empirical results from this study support the predictions of the standard open economy macroeconomic theory (the Mundell-Fleming model) in one half of the cases. This dissertation also confirms earlier findings on the sensitivity of Granger causality tests to lag length selection.

INTRODUCTION

It is widely accepted in macroeconomics that there is a positive relationship between the rate of growth of the money supply and the rate of growth of aggregate income. However, there is far less agreement on the direction of causation between these two variables. Keynesians and monetarists have debated this issue for years without reaching a consensus.

Several approaches have been taken to help resolve this controversy. One influential avenue of research has been the application of sophisticated econometric techniques to investigate the relationship between money and income. Sims [1972] was the first to take up this task using data for the United States. Taking advantage of a criterion developed by Granger [1969] for detecting causal relationships, he devised a procedure to test for the direction of causation between money and income. He concluded that for postwar US data, money caused income in the Granger sense. This finding was generally seen as evidence in support of monetarism. Since the publication of this seminal paper, a large number of studies on the empirical relationship between money and income have been undertaken for the U.S. as well as for other countries. Unfortunately, the conclusions of these studies are often contradictory. Even studies following closely related methodologies came up with puzzlingly dissimilar results. A new controversy - the statistical relationship between money and income - has thus been created.

Over the last several years, a number of advances have been made in time series analysis. Some of these advances, particularly those relating to the concepts of integration and cointegration, and the stationary nature of economic time series, promise to help resolve the many contradictory findings of the various studies on money-income causality. Recently, a handful of researchers, using some of these new advances, have been able to reconcile the results of most of the recent studies on US money-income causality. However, the scope of these researchers has been rather limited as they dealt only with the United States, and their work was confined to a closed economy framework.

The object of this project is to extend the recent work on money-income causality in two directions:

1. Reexamine the empirical evidence on money-income causality within an open economy framework;

2. Expand the investigation to other economies.

This dissertation is organized as follows. Chapter I presents a review of the econometric tools relevant to the object of this project: time series analysis and Granger causality. Chapter II reviews the literature on money-income causality. Chapter III discusses the new advances in time series analysis. An exposition of the standard open-economy macroeconomic theory is presented in Chapter IV. The methodology used in this project is outlined in Chapter V. Chapter VI presents the results. Finally, chapter VII discusses the results and concludes.

CHAPTER I

ECONOMETRIC REVIEW

Introduction

Two theoretical elements are central to the empirical investigation of the relationship between money and income. The first is a criterion based on a particular definition of causality developed by Granger [1969] that allows the empirical testing of the form and direction of causality between economic variables. The other is time series analysis. Since the Granger criterion is applied only to temporal systems, a presentation of some relevant time series concepts and models is required before discussing Granger causality.

A. Time Series Analysis

Although time series analysis is rooted in physics and engineering, its methodology is mainly statistical and its applications cover a wide spectrum of fields, from astrophysics to neurophysiology. Time series models have recently been enjoying a growing popularity among economists. A chief advantage of such models in economics is that they avoid the difficulties associated with structural models, such as the imposition of prior restrictions. These models are "atheoretical" in that economic theory plays only a limited role in their specification. They rely only on the past history of one or more variables to model the behavior of this variable[1]. The principal application of time series models has been in forecasting. The systematic pattern in the past movements of a variable are captured by the model which is then used to predict the future behavior of this variable.

Time series analysis assumes that the series of interest is generated by a stochastic process (i.e., that each value in the series is randomly drawn from a probability distribution). Time series modeling is an attempt to capture the characteristics of the series' randomness. These characteristics allow one to make inferences about the probabilities associated with the future values of the series. There are a number of time series modeling techniques. The most popular techniques among economists are briefly described below.

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[1] See Box and Jenkins [1970] for a detailed exposition of time series analysis. Priestley [1988] presents the more recent developments in time series analysis.

1. Univariate Models:

Consider a single discrete (i.e., measured at equal intervals of time) time series X_t. A time series model can be specified by identifying a function F of past observations which transforms that series into a white noise process:

$$\Sigma f_i X_{t-i} = e_t \tag{1.1}$$

A white noise process fulfills the following conditions:

i) $E[e_t] = 0$

ii) $E[e_t^2] = \sigma^2$

iii) $E[e_s e_t] = 0$ for $t < s$.

It is thus a succession of zero mean random variables, having a constant variance σ^2. Making use of the lag operator L, defined by $LX_t = X_{t-1}$, $L^2X_t = X_{t-2}, \ldots$, Equation (1.1) can be rewritten as:

$$F(L)\ X_t = e_t$$

where $F(z) = \Sigma f_i z^i$.

This can be solved to yield:

$$(1.2) \qquad X_t = F^{-1} (L) e_t$$

Given certain conditions are met (see Priestley [1988]), Equation (1.2) can be rewritten as:

$$(1.3) \qquad X_t = A(L) e_t$$

Equation (1.3) is a general linear time series model representing X_t as a linear combination of present and past values of a white noise process e_t. The practicality of this general model, however, is fairly limited since it includes an infinite number of parameters and, therefore, cannot be fitted directly to the data. To make it workable, some assumptions need to be made. These assumptions give rise to a standard set of finite parameter models which are special cases of the general linear model as represented by Equation (1.3).

a. Autoregressive model. Assuming that A(z) may be approximated by a finite-order polynomial such as:

$$A^{-1}(z) = 1 + \phi_1 z + \phi_2 z^2 + \ldots + \phi_p z^p$$

then the general linear model converts to the autoregressive model of order p:

(1.4) $$X_t + \phi_1 X_{t-1} + \phi_2 X_{t-2} + \ldots + \phi_p X_{t-p} = e_t$$

or $$\phi(L) X_t = e_t$$

This model is commonly referred to as an AR(p) model. It expresses the current value as the sum of its past values plus a white noise disturbance term.

<u>b. Moving average model.</u> Assuming that A(z) may be approximated by a finite-order polynomial such as:

$$A(z) = 1 + \sigma_1 z + \sigma_2 z^2 + \ldots + \sigma_q z^q,$$

then the general linear model reduces to the moving average model of order q:

(1.5) $$X_t = e_t + \sigma_1 e_{t-1} + \sigma_2 e_{t-2} + \ldots + \sigma_q e_{t-q}$$

or $$X_t = \sigma(L) e_t$$

This model is commonly referred to as MA(q). A MA model expresses the current value of X as the sum of present and past disturbance terms.

c. Autoregressive-moving average model. If certain conditions are satisfied, a general linear model can be approximated by either an AR or MA model of sufficiently high order. However, a more parsimonious finite parameter model representation can be obtained by combining the attributes of an autoregressive model and those of a moving average model. The resultant model is an autoregressive-moving average model, commonly referred to as ARMA(p,q):

$$X_t + \phi_1 X_{t-1} + \ldots + \phi_p X_{t-p} = e_t + \sigma_1 e_{t-1} + \ldots + \sigma_q e_{t-q} \tag{1.6}$$

In operator form, Equation (1.6) can be rewritten as:

$$\phi(L) X_t = \sigma(L) e_t \tag{1.7}$$

2. Multivariate Models:

The AR(p), MA(q) and ARMA(p,q) models are fairly limited because they use data on only one variable and therefore neglect other potentially pertinent information. This limitation is overcome by the use of multivariate time series models. In a multivariate time series model, the current value of the variable X_t is modeled as a function, not only of its past values plus its random disturbance term, but also of the current and past values of other variables and their random disturbance terms:

(1.8) $X_t = \Sigma\, a_i\, X_{t-i} + e_{1t} + \Sigma\, b_i\, Y_{t-i} + e_{2t} + \ldots$

A fairly general multivariate time series model is the Vector Autoregression (or VAR) model. A VAR model is a dynamic system, composed of a vector of variables, where each variable depends, not only on its own past values, but also on those of each of the other variables in the system[2]. Thus, in the VAR all the variables in the system are considered to be endogenous. An n-variable VAR system is formed of n separate equations, all having the same explanatory variables. A VAR model can be represented as follows:

(1.9) $X_t = D_t + \Sigma\, B_i\, X_{t-i} + U_t$

where X_t is a vector of n variables, D_t is an nx1 vector that captures the deterministic component of X_t, B_i is an nxn matrix of coefficients, U_t is an nx1 vector of white noise disturbances satisfying the following conditions:

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[2] Sims [1980a, 1982], Litterman [1979, 1980, 1982], Sargent [1979], Gordon and King [1982], and Hakkio and Morris [1984] provide good expositions of the VAR technique.

i) $E[U_t] = 0$

$$E[U_t \, U_s'] = \begin{cases} \Omega & \text{if } t=s \\ 0 & \text{otherwise} \end{cases} \quad \text{ii)}$$

iii) $E[X_t \, U_s'] = 0$ for $t < s$.

Besides their usefulness for forecasting, VAR models can also be used to formally test economic theories and to analyze the historical dynamics of the economy. Because of their limited reliance on economic theory, VAR models could be used by economists with different views of the true structure of the economy, such as Keynesians and monetarists, to forecast economic variables or to estimate relevant parameters such as the interest-elasticity of income.

3. Stationarity:

Stationarity is an important property of the stochastic process that a time series model attempts to describe because it guarantees that the basic characteristics of the process do not change over time. Econometric techniques require stationarity. Also, for a time series X_t to be equivalently approximated by an AR(p), an MA(q) or an ARMA(p,q) model, it must be stationary. A process is stationary if it satisfies the following conditions (Judge et al. [1985], page 226):

i) $E[X_t] = \mu$ for all t

ii) $\text{var}\,[X_t] < \infty$ for all t

iii) $\text{cov}\,[X_t, X_{t+k}] = E[(X_t - \mu)(X_{t+k} - \mu)] = \delta_k$ for all t and k.

Thus, a stationary process has a constant mean, a finite and constant variance, and covariances that are independent of time. If a process is stationary, its stochastic properties are invariant with respect to time. Moreover, a stationary process tends to constantly return to its mean value. A non-stationary process, on the other hand, has a mean that varies with time so that the process will have a different mean value in different time periods.

B. Granger Causality

A major objective of empirical research in economics is the elucidation of causal relationships among variables. Traditionally, this task has been carried out by analyzing the correlations between them. However, a finding of high correlation between two variables does not necessarily mean that they are causally related. If they are both associated with a common set of variables, they will be correlated without being causally related. On the other hand, because correlation is a measure of only linear association, two variables may be functionally related yet uncorrelated. Even in the cases where correlation means causation - when the system under consideration is entirely linear and when all the variables within that system are identified - it is still not clear which of the variables causes the other.

1. Definitions:

Granger [1969] proposed a definition of causality that addressed these problems in the case of temporal systems. Noting that the flow of time is central in causality, he defined causality in terms of predictability: a variable X "causes" a variable Y if present Y can be predicted better by using past values of X than by not doing so, all other information (including the past of X) being used in either case. This definition has proved very useful as it can be tested empirically.

The formal definition of Granger causality follows. Given two stationary stochastic time series X_t and Y_t, let us define:

i) $\overline{X}_t$ as the set of past values $\{X_{t-i}, i=1,2,\ldots, \infty\}$ of X and $\overline{Y}_t$ as the set of past values $\{Y_{t-i}, i=1,2,\ldots, \infty\}$ of Y.

ii) U_t as the set of all information accumulated since time t-1 and U_t-Y_t as the set of all available information apart from the series Y_t. $\overline{U}$ and $\overline{U-Y}$ are thus the sets of past U and past U-Y, respectively.

iii) $\sigma^2(X/\overline{X})$ as the minimum predictor error variance of X using only past values of X.

Then,

a. Unidirectional causality: if $\sigma^2(X / \overline{U}) < \sigma^2(X / \overline{U-Y})$, then it can be said that Y is causing X. Symbolically, this is denoted as Y => X.

b. Bidirectional causality: if $\sigma^2(X / \overline{U}) < \sigma^2(X / \overline{U-Y})$ and $\sigma^2(Y / \overline{U}) < \sigma^2(Y / \overline{U-X})$, then both X is causing Y and Y is causing X. This relationship is also called feedback (Y <=> X).

c. Independence: if $\sigma^2(X / \overline{U}) = \sigma^2(X / \overline{U-Y})$ and $\sigma^2(Y / \overline{U}) = \sigma^2(Y / \overline{U-X})$, then there is no causal relationship between X and Y.

2. Causality Tests:

A number of alternative tests based on Granger's criterion for causality have been developed. The best known among them are Sims test and the direct Granger test.

a. Sims causality test.

Soon after Granger's [1969] introduction of the criterion for identifying causal relationships, Sims [1972] developed a practical test for investigating causal relationships between economic variables.

In his Theorem 2, Sims stated:

> When $[\begin{smallmatrix}X\\Y\end{smallmatrix}]$ (where X and Y are jointly covariance stationary stochastic processes) has an autoregressive representation, Y can be expressed as a distributed lag function of current and past X with a residual which is not correlated with any values of X, past or future, if, and only if, Y does not cause X in Granger's sense [p. 544-545].

He then went on to say that "... only in the special case where causality runs from X to Y can we expect that no future values of X would enter the regression if we allowed them" [p. 545].

Thus, in a regression of Y on past, present and future values of X, the null hypothesis of no causality from Y to X requires that all the coefficients on the future values of X be equal to zero. The above theorem is readily translated into a formal statistical test of causality. Given a bivariate model including time series X and Y, X is regressed on past, present and future Y:

$$(1.10) \qquad X_t = a + \Sigma^{n}_{i=-p} b_i Y_{t-i} + e_t$$

$$(1.11) \qquad Y_t = c + \Sigma^{n}_{j=-p} d_j X_{t-j} + u_t$$

where a and c are constants, b_i and d_j are least squares estimates, e_t and u_t are residuals; and the series X_t and Y_t have been prefiltered to make them stationary.

To test whether X Granger-causes Y, an F-test is conducted on Equation (1.10) with the null hypothesis being that $b_i=0$ for $i=-p, \ldots, -1$. A rejection of the null hypothesis would mean that X Granger-causes Y: including past values of X in the regression contributes significantly to the explanation of future Y.

<u>b. Direct Granger test.</u> This test was suggested by Granger [1969] and further developed by Sargent [1976]. For this reason it is also sometimes referred to as the Granger-Sargent test or the Sargent test. It can be illustrated using a two-variable distributed lags model.

$$(1.12) \qquad Y_t = k + \Sigma^{p}_{i=1} a_i X_{t-i} + \Sigma^{p}_{i=1} b_i Y_{t-i} + e_t$$

where k is a constant, a and b are least squares estimates and e_t is the residual. To test the null hypothesis that X does not cause Y is analogous to testing that the X's make no explanatory contribution to the regression Equation (1.12). If the computed F-statistic based on the null hypothesis that $a_i=0$ for $i=1,2,\ldots,p$ is significant, then it can be inferred that X causes Y. If, on the other hand, the F-statistic is not significant then an absence of causality is implied.

Sims test and the direct Granger test have been used extensively for various purposes. For example, Elliott [1975] used the Sims test to check the assumptions about the exogeneity of the explanatory variables in the St. Louis model and Mehra [1978a] applied this test to various money demand equations to test the exogenous nature of the variables in these equations. The direct Granger test (or some version of it) was utilized by Sargent [1976] to identify the causal relationships among the variables of his "classical" macroeconomic model, and by Mehra [1977] to test for wages-prices causality.

c. Causality testing with VARs. The introduction of the VAR technique in the early 1980's allowed the extension of Granger causality testing to large collections of variables. The use of VAR models for causality testing can be illustrated with a two-variable VAR model. As discussed earlier, a VAR represents a closed, dynamic system where all the variables are endogenous.

$$X_t = a(L)\ X_t + b(L)\ Y_t + e_t \qquad (1.13)$$

$$Y_t = c(L)\ X_t + d(L)\ Y_t + u_t \qquad (1.14)$$

Granger causality between X and Y can be examined by testing the following null hypotheses:

$$b(L) = 0$$

and $$c(L) = 0$$

If the first hypothesis is rejected but the second one is not, the implication is that Y causes X. If the second hypothesis is rejected but the first one is not, this implies that X causes Y. If both hypotheses are rejected, there is feedback between X and Y. Finally, if neither can be rejected, then X and Y are independent.

CHAPTER II

REVIEW OF THE LITERATURE

Although Friedman and Schwartz published a far-reaching empirical study on money-income causality as early as 1963 (Friedman and Schwartz, 1963), it was not until after Granger developed his causality criterion that systematic investigations using formal econometric methods were undertaken.

The statistical investigation of the relationship between money and income started with Sims' [1972] seminal paper "Money, Income and Causality". In this paper, Sims developed a causality test based on the Granger criterion and applied it to the US data on money and income. He used quarterly data for the money supply (M1) and income (nominal GNP) over the period 1947-1969. To remove the serial correlation in the error terms, he prefiltered the logarithm of the original data using a filter in the form of $(1 - 0.75L)^2$ which he claimed "approximately flattens the spectral density of most economic time series [p. 545]"[3]. On the basis of F-tests he found the future values of GNP to be highly significant in explaining M1, whereas the future values of M1 were not significant in explaining GNP. Replacing M1 with the monetary base (currency plus reserves adjusted for changes in reserve requirements), or substituting real GNP for nominal GNP did not significantly alter these results. He concluded that US postwar data supported the hypothesis that causality was unidirectional from money to income, but rejected the hypothesis of unidirectional causality from income to money. Although this conclusion could be compatible with many theories, it was generally seen as supporting the monetarist view that "money matters" for real output.

Sims' study has had a considerable impact on the economics profession. In both the United States and in other countries, it stimulated a large number of studies on the direction of causality among various economic time series. Causality testing quickly became an important component in the economist's tool kit. One of the earliest researchers to employ Sims' procedure was Elliott [1975] who used it to test the exogenous character of the explanatory variables of the St. Louis model. In a trivariate model with money supply, nominal GNP and government expenditures, he found money supply

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[3] Nerlove (1964) applied filters of the type $(1-kL)^p$ to seasonally adjusted time series to detrend them. He found that using filters with $k=0.75$ and $p=1, 2, 3$ can flatten the spectral density of a large number of economic time series.

to have a substantial influence on GNP, but GNP had no marked influence on money. His results, which corroborated Sims', allowed him to raise a number of statistical objections against the St. Louis model. Using Sims' procedure, Mehra [1977] tested for causality between US money, wages and prices; and Mehra [1978a] investigated the causal relationship among the variables of the US money demand equation. Mehra [1978b] repeated Sims' study using a more recent sample (1952I-1972IV). He found money to have a permanent effect on nominal GNP and the price deflector, and a short run effect on real GNP. He also found a feedback relationship between money and the GNP deflator.

Sims' work prompted many researchers to investigate the relationship between money and income in different countries. These studies include Barth and Bennett [1974], Sharpe and Miller [1975], Auerbach and Rutner [1978] (Canada); Williams, Goodhart and Gowland [1976] (United Kingdom); Atesoglu and Tillman [1980] (Korea); DyReyes [1974] (United States, Canada, Japan); DyReyes, Starleaf and Wang [1980] (Australia, Canada, Germany, Japan, United States, United Kingdom)[4]. The results of these studies did not always agree with Sims' findings for the United States, nor with each other. Using an approach identical to Sims' [1972], Barth and Bennett [1974] found evidence of a feedback relationship between Canadian money and

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[4] In this section only studies conducted within a closed economy framework are surveyed. Open economy studies are left for Chapter IV.

income, while DyReyes [1974] and Auerbach and Rutner [1978] found no evidence of causality in either direction. On the other hand, Sharpe and Miller [1975] claimed a unidirectional causality from Canadian money to Canadian income, as did DyReyes, Starleaf, and Wang [1980]. Atesoglu and Tillman [1980] used Sims' [1972] methodology to investigate the relative influences of money and autonomous spending on GNP in Korea over the period 1960-1974. Their results supported the conclusion of bidirectional causality between money and income. In an investigation of money-income causality in six different countries, DyReyes, Starleaf and Wang [1980] found evidence of unidirectional causality from money to income in Canada and Australia, unidirectional causality from income to money in the United Kingdom, bidirectional causality in the United States and Japan, and no relationship between money and income in Germany. Williams, Goodhart and Gowland [1976] obtained results supporting a conclusion of unidirectional causality from income to money in the United Kingdom.

Many objections were raised at Sims' procedure and results. The most serious ones were based on methodological grounds. First, his use of a particular filter to eliminate serial correlation in the regression residuals was called into question. It was shown that the conclusions on the presence and direction of money-income causality based on Sims' test were highly sensitive to the particular filter chosen. For instance, using the same data base as Sims' and the same testing procedure except for a different filter, Feige and Pearce [1979] found no evidence of causality between money and GNP. DyReyes, Starleaf and Wang [1980], using a different filtering technique, reported results compatible with bidirectional causality between money and income for the United States. More recently, Geweke, Meese and Dent [1983] examined a number of causality tests and found Sims' test to be sensitive to prefiltering, as did Kraft and Kraft [1977]. Williams, Goodhart and Gowland [1976] also rejected Sims' filtering methodology.

Second, the use of alternative testing procedures for money-income causality did not always support Sims' findings of unidirectional causality from US money to US income. Feige and Pearce [1979] applied Sims' test and two alternative tests to the same data set. The first alternative test, called the Haugh-Pierce test, is a cross-correlation technique developed by Haugh [1972, 1976] and Pierce [1977][5]. The other alternative test is the direct Granger test. Based on the Haugh-Pierce test, Feige and Pearce could not reject the null hypothesis that money and income were independent. The direct Granger test results led them to the conclusion that there was no significant evidence of causality between money and income. Thus, the results from the two alternative tests contradicted

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[5] The Haugh-Pierce test is more a test of independence than a true causality test. It has been criticized by Schwert [1977] for its low power, and by Sims [1977] who contended that this test was biased in favor of the null hypothesis of independence.

the conclusions based on Sims' test. More recently, Chowdhury [1987] investigated the sensitivity of causality testing to the technique used. Applying three alternative causality tests (Sims', Sargent's and Haugh-Pierce's) to detect a causal relationship between sunspot cycles and economic activity in the United States, he concluded that this relationship was indeed sensitive to the particular test used.

The results of money-income causality tests have been shown to depend on whether the series are detrended or not. In an investigation of the effects of detrending on Granger causality tests, using US quarterly data on nominal and real GNP and M1, Kang [1985] found that detrending had a tendency to remove or weaken causal relationships, whereas no detrending tended to introduce or enhance causal relationships. Finally, Sims' results could not be generalized to other countries as the money-income causality tests for different countries produced a variety of results.

In 1980 Sims introduced the Vector Autoregression (VAR) technique (Sims [1980a]). A major advantage of the VAR technique is that many of the standard assumptions made by econometricians in model building are no longer necessary and yet economically meaningful hypotheses can still be tested. Economic theory enters only in the process of choosing the relevant variables. This new technique provided Sims the opportunity to reexamine the empirical evidence on money-income causality. Using VAR systems with twelve lags of each variable (in logarithmic form), a constant term but no trend, and monthly data, Sims [1980b] analyzed the responses of the variables in the systems to their innovations using a variance decomposition procedure[6]. In a VAR composed of money (M1), output (Industrial Production Index) and prices (Wholesale Price Index), he found that money innovations accounted for a substantial portion (37 percent) of the variance in industrial production and that money was explained primarily by its own innovations (97 percent) over the period 1948-1978. Sims claimed that this was tantamount to evidence of unidirectional causality running from money to industrial production, a result confirming his 1972 finding that supported monetarist views. However, when a short term interest rate was added to the VAR system, the proportion of the variance in industrial production explained by innovations in money stock dropped to only 4 percent. Moreover, innovations in interest rates accounted for 56 percent of the variance in the money stock and 30 percent of the variance in industrial production. Sims concluded that in a four-variable system including prices and interest rates, money no longer Granger-caused industrial production and he attributed the observed comovements of industrial production and money stock to a common response to unexpected changes in the interest rate.

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[6] "Innovations" are defined as follows by Sims [1972], p. 543: "The innovations in the stochastic process X_t is that part of X_t which can not be predicted from X's own past (i.e., the residual part in a regression of X_t on its own past)."

These results, if correct, raise serious questions about monetarism. If one accepts that monetary shocks have had an insignificant role in postwar business cycles, one has to agree that a monetarist rule making the quantity of money more predictable is of little value. On the other hand, the empirical finding that monetary shocks have no significant impact on output lends powerful support to equilibrium real business cycle theories. These theories, which have attracted considerable renewed interest over the past decade, maintain that fluctuations in real quantities such as output, consumption and investment are due to real rather than monetary causes. A key implication of these models is that money has only a limited role in the determination of output (King and Plosser [1984], Bernanke [1985], Eichenbaum and Singleton [1986]).

As expected, Sims' [1980b] results and claims intensified the controversy over the statistical relationship between money and income. Litterman and Weiss [1985] replicated Sims' work using a longer sample period (1948:I to 1983:II) and quarterly data. Their findings generally supported Sims', which led them to conclude that "... most of the dynamic interactions among the key variables can best be explained as arising from an economic structure in which monetary phenomena do not affect real variables. Thus, we conclude that monetary instability has not played an important role in generating fluctuations [p.129]". However, many other researchers challenged Sims' results. They showed them to be sensitive to the lag-length specification of the VAR used, to whether time trends are included, to whether levels or differences of the variables are used, and to the sample period chosen. Hsiao [1981], Guilkey and Salemi [1982], Geweke [1984], Kang [1985, 1989], Thornton and Batten [1985], Serlitis [1988], and Urbain [1989] showed that Granger causality results could be very sensitive to the choice of the lag length. For example, Thornton and Batten [1985] examined US money-income causality using bivariate models in which the lag lengths were selected through five different criteria: two ad-hoc (4-4 and 8-8 lags), and three statistical[7]. In many instances these models produced contradictory causality results.

In separate studies, King [1984] and Runkle [1987] found that adding a linear time trend to the four-variable system (money, output, prices and interest rates) resulted in a significant increase in the fraction of the variance of output explained by innovations in money. Litterman and Weiss [1985] came to similar conclusions when they added a linear as well as a quadratic time trends.

The results of money-income causality tests varied when the tests were performed using differences of the variables instead of levels. Eichenbaum and Singleton [1986], using

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[7] These are Akaike's [1969a] Final Prediction Error, the Bayesian Estimation Criterion developed by Geweke and Meese [1981], and a procedure suggested by Pagano and Hartley [1981].

monthly data, reported no evidence of causality between money and output in a bivariate system or in multivariate systems including inflation and interest rates when log differences of these variables were used. When log levels with a trend were used in place of log differences, they found more evidence that money Granger-caused output both in the bivariate and the multivariate systems. This latter result was, however, sensitive to sample period changes. In a five-variable VAR including real stock and bond returns as proxies for interest rates, they found money innovations to account for 46 percent of the variation in detrended output over the sample period 1959:2 through 1983:4. But when the sample period excluded the 1980's (1959:2 through 1979:12), money innovations explained only 12 percent of the variation in detrended output. Hsiao [1981] also found the qualitative conclusions from Granger causality testing to be sensitive to filtering: the direction of the causality between money and income when the data were once-differenced was exactly the opposite of that when the data were twice-differenced.

Finally, King [1984], Christiano and Eichenbaum [1986] and Stock and Watson [1989] all found the results of money-income causality to be sensitive to the sample period.

The foregoing survey identifies a number of causes for the disparate results of money income causality investigations. Though the introduction of the VAR technique allowed the development of new causality tests, it did not alleviate most of the problems with Granger causality testing. Major difficulties, such as the lag-length specification and the filtering technique used to obtain stationarity, remained. Over the course of the last several years many advances have been made in time series analysis that provide ways to resolve these problems. These new developments are presented next.

CHAPTER III

STATIONARITY AND CAUSALITY

From the previous chapter, it is clear that many of the contradictory results in the various studies of money-income causality come from the disparate methodologies used to achieve stationarity in the time series under consideration. Over the last several years, considerable attention has been devoted to stationarity in the econometrics literature. The outcome of this research has been a better understanding of the stationary nature of economic time series and the development of procedures for the detection and correction of non-stationarity.

A. Stationarity of Economic Time Series

Two fundamentally different classes of non-stationary processes can be distinguished. The first class of processes, called trend-stationary, is made up of those processes which can be expressed as a deterministic function of time (the deterministic component), plus a stationary stochastic process (the stochastic or cyclical component). Until recently, most economic time series were generally assumed to belong to this class of processes, with the deterministic component usually being associated with long-run or permanent movements and the stochastic component being attributed to transitory causes. A second class of non-stationary processes, called stochastic-stationary (or difference-stationary), has received intensive attention over the last few years. To illustrate the nature of this non-stationarity, let us consider a simple AR(1) model.

$$X_t = aX_{t-1} + e_t \tag{3.1}$$

This model can be written as a difference equation:

$$(1 - aL)\ X_t = e_t\ ; \qquad t = 1,\ 2,\ 3,\ \ldots \tag{3.2}$$

This equation is solved to yield:

$$X_t = a^t X_0 + e_t + a\ e_{t-1} + \ldots + a^{t-1}\ e_1 \tag{3.3}$$

where X_0 is the initial value. The coefficient a can take three sets of values[8]:

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[8] For conciseness, only positive values for a are considered here, but parallel conclusions can be drawn when a takes on negative values (see Fuller [1976]). a can also be a complex number (see Ahtola and Tiao [1984]).

i) $0 < a < 1$

ii) $a = 1$

iii) $a > 1$

From equation (3.3) it is easy to see that the value of a is critical to the behavior of the series.

a) For $0 < a < 1$, the influence of the initial value as well as that of the distant past shocks will die out as time t increases, and the series will tend to converge toward its original value. In this case, a random disturbance will have only a temporary impact on the series.

b) For $a = 1$, the "unit root" case, the initial value and distant past shocks all have the same weight of 1 in all time periods. In this case, commonly referred to as the random walk, the series tends to move about randomly, with no tendency to return to its original value. In other words, a random disturbance will have a permanent effect on the series.

c) For $a > 1$, the "explosive" case, the influence of the initial value and that of the distant past shocks increase exponentially with time.

Only in the first case, where the absolute value of the coefficient a is less than one, will the AR(1) model in equation (3.1) fulfill the stationarity conditions. In the other two cases the structure of the process changes over time and, therefore, the process is non-stationary. A necessary condition then for the AR(1) process to be stationary is that the coefficient a be less than unity.

The illustration can readily be extended to the more general autoregressive AR(p) model. This model expresses the current value of X as a weighted average of past observations going back p periods, and a random white noise disturbance term e_t:

$$X_t = a_1 X_{t-1} + a_2 X_{t-2} + \ldots + a_p X_{t-p} + e_t \tag{3.4}$$

The characteristic equation of this more general case will have several roots, some of which are possibly complex roots. In this case, for the stationarity conditions to be fulfilled, all the roots of the characteristic equation must lie outside the unit circle.

Before any analysis is performed, the time series under consideration must be made stationary by removing their deterministic and/or stochastic trends. The trend removal method to be used depends on the nature of the non-stationarity at hand. The two most common trend removal methods are regression on time (or a polynomial of time), and first-differencing. If a series is indeed trend-stationary, either of these methods effectively removes its deterministic trend. But, first-differencing also introduces an artificial unit root into the moving average specification of the underlying process. If, on the other hand, the time series is stochastic-stationary, the stochastic trend is removed by taking its first (or higher) difference. But regressing it on time creates periodicity and autocorrelations in the residuals. These issues were first addressed by Chan, Hayya and Ord [1977]. Their work has been extended in influential papers by Nelson and Kang [1981, 1984]; Phillips and Durlauf [1986]; and Cochrane [1987]. It is now clear that the improper use of a trend removal method can have serious consequences, as it causes one to infer a time series structure that is different from the actual one and this will lead to spurious results.

As mentioned previously, until recently it was generally assumed that most economic time series were trend-stationary. However, Nelson and Plosser [1982] established that most US macroeconomic time series did in fact belong to the stochastic-stationary class of processes. The series they characterized as stochastic-stationary were real GNP, nominal GNP, real per capita GNP, Industrial Production, employment, GNP deflator, consumer prices, nominal wages, real wages, money stock, money velocity, interest rates, and common stock prices. Only the unemployment rate could not be characterized as stochastic stationary. Nelson and Plosser's findings have important implications.

First, the general assumption that business cycles can be described as fluctuations around a deterministic trend is no longer valid. Fluctuations in a time series that is stochastic-stationary affect not only the cyclical component, but also the trend component. This fact has implications for the explanations of output fluctuations, for example. If the volatility of output is mainly due to fluctuations in the stochastic trend, then aggregate demand fluctuations, such as those caused by the effects of monetary policy, may not be very important in explaining output fluctuations. However, supply-side shocks, such as those due to technology and labor supply, are important determinants of these output fluctuations.

The presence of a stochastic trend also has important implications for long-run forecasting. When the series to be forecasted has a stochastic trend, the confidence interval around the optimal forecast increases continuously as the forecast horizon increases. This is because the variance associated with the forecast of a stochastic trend tends to increase towards infinity as the forecast horizon is extended (Balke [1991], Dickey, Bell and Miller [1986]). Third, the presence of stochastic trends has important implications for the use of conventional econometric techniques in hypothesis testing. This point will be discussed later.

Nelson and Plosser's study spurred many other researchers to investigate the stationary nature of a variety of economic time series. A small sample of this work includes Meese and Singleton [1982], Perron [1986a, 1986b, 1986c], Phillips and Durlauf [1986], Stock and Watson [1986, 1987], Perron and Phillips [1986], Clark [1987], Cochrane [1987], Campbell and Mankin [1987]), Campbell and Deaton [1987], Mankiw and Shapiro [1985], Kleidon [1987], Schwert [1987], and Wasserfallen [1986]). The evidence generated by this literature is overwhelmingly supportive of the hypothesis that a large number of economic time series are best described as stochastic-stationary. This finding is significant as it casts doubts on the results of a large number of econometric studies. Prior to Nelson and Plosser's study, most economists assumed economic time series to be trend-stationary and they selected a trend removal method more or less arbitrarily. However, it is now evident that:

i) most macroeconomic time series are stochastic-stationary; and

ii) spurious results are obtained when an inappropriate trend removal method is applied to a stochastic-stationary series.

These findings underscore the need in empirical work to first ascertain the nature of the non-stationarity at hand before engaging in any analysis. Stochastic non-stationarity is generally signalled by the presence of a unit root. Recently, several researchers have devised formal tests to detect the presence of a unit root. D. A. Dickey and W.A. Fuller pioneered the development of such tests (Dickey [1976], Fuller [1975], Dickey and Fuller [1979, 1981]). They were soon followed by a large number of researchers (see, for example, Hasza [1977]; Hasza and Fuller [1979]; Evans and Savin [1981, 1984]; Said and Dickey [1984, 1985]; Phillips [1987]; Phillips and Perron [1988]; Schwert [1987]; Sargan and Bhargava [1983]; Dickey and Pantula [1987]; Dickey, Hasza and Fuller [1984]; Oliaris, Park and Phillips [1988]; Solo [1984]. The most popular unit root test to date remains the Dickey-Fuller test. To run this test, the first difference of the variable to be tested is regressed on its own lagged level, a constant, a time trend, and lagged first differences. The null hypothesis is that the series contains a unit root (i.e., it is non-stationary). This implies that the coefficient on the lagged level should be zero. The test statistic is the ratio of the estimated coefficient to its standard error. However, this statistic does not have the usual t-distribution. Dickey and Fuller [1979] provide critical values for this statistic.

B. Cointegrated Processes

In univariate models, the proper way to detrend a stochastic-stationary series is to take its difference. A series that is differenced d times to make it stationary is said to be integrated of order d. Differencing a univariate series eliminates the unit root present in it and thus makes it stationary. When dealing with multivariate models, however, the situation is more complex. The reason is that the number of unit roots in a multivariate model is not necessarily equal to the sum of the number of unit roots in the constituent univariate series. In other words, there may be stochastic trends common to two or more of the variables comprising the multivariate model. Common stochastic trends signal the presence of a long run relationship between the variables.

Processes characterized by common stochastic trends are called cointegrated processes. Engle and Granger [1987] provide an exact definition of cointegration. A vector time series X_t is said to be cointegrated of order d, b, denoted $X_t \sim CI(d,b)$ if:

i) all components of X_t are integrated of order d (i.e., they have d unit roots in their univariate representations); and

ii) there exist one or more linear combinations of the components of X_t, $Z_t = \alpha X_t$, with Z_t being integrated of order d - b, b > 0.

They call the vector α the "cointegrating vector".

Cointegration can be illustrated through the following simple bivariate example due to Engle and Granger (1987):

$$X_t + bY_t = u1_t \qquad \text{with} \qquad u1_t = u1_{t-1} + e1_t \tag{3.5}$$

$$X_t + dY_t = u2_t \qquad \text{with} \qquad u2_t = au2_{t-1} + e2_t \tag{3.6}$$

where $| a | < 1$, and $e1_t$ and $e2_t$ are white noise disturbances. The reduced form of this system will have X_t and Y_t as a linear combination of $u1_t$ and $u2_t$. Since $u1_t$ is integrated of order 1, so will X_t and Y_t. However, Equation (3.6) represents a particular combination of X_t and Y_t that is stationary. Therefore, the system composed of X_t and Y_t is cointegrated of order (1,1).

The existence of cointegrated processes was first suggested by Granger [1981]. He proposed that even though the individual elements of a vector of time series may be stochastic-stationary, there may be linear combinations of these elements that are stationary without differencing. Since the publication of Granger's [1981] paper, the theory of cointegrated processes has received increasing attention in the econometric literature. A small sample of the research in this area includes Granger [1983, 1986], Granger and Weiss [1983], Phillips and Durlauf [1986], Stock [1987], Stock and Watson [1987], Engle and Granger [1987, 1991], Engle and Yoo [1987], and Campbell and Shiller [1987].

When a vector of time series is cointegrated, a dilemma arises on how much differencing to perform. Because the individual time series are stochastic-nonstationary, some differencing needs to be performed. However, differencing all the series according to their univariate properties will result in an over-differenced multivariate model[9] that does not have an invertible moving average representation. Recently, though, methods have been devised to deal with this problem. These methods are based on error correction models. Error correction models incorporate equilibrium relationships that may be suggested by an economic theory of the long run. The idea behind them is that some of the disequilibrium that may exist in the relationship in one period is corrected in the next. A common example is price determination: the change in price in period t may be a function of the degree of excess demand in period t-1. Phillips [1957] and Sargan [1964] were among the first to develop error correction models and this

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[9] "Overdifferencing" occurs when a series is differenced more times than is necessary to make it stationary. In this case, the invertibility conditions are not satisfied as the moving average representation of the series now contains a unit root.

class of models has since been widely used in economics. In recent years, there has been a resurgence of interest in these models (see, for example, Davidson, Hendry, Srba, and Yeo [1978], Hendry and von Ungern-Sternberg [1981], Campbell and Shiller [1987], and Salmon [1988]).

The relationship between error correction models and cointegration was first suggested in Granger [1981]. Granger [1981] and Engle and Granger [1987] stated and proved that if $X_t \sim CI(1,1)$, then it has an error correction representation, and conversely, cointegrated models could be represented by error correction models. This can be illustrated using a simple bivariate model composed of time series X_t and Y_t, both I(1). If there exists a constant d, such that

$$Z_t = X_t - dY_t \tag{3.7}$$

is I(0), then X_t and Y_t are cointegrated. The relationship $X_t=dY_t$ can be seen as a long-run or equilibrium relationship, and Z_t above can be considered as the equilibrium error, or the degree to which the system X_t and Y_t is out of equilibrium. Given that X_t and Y_t are both I(1) and are cointegrated, Granger [1981] and Engle and Granger [1987] show that they will be generated by an error correction model having the form:

$$\Delta X_t = \gamma_1 Z_{t-1} + \text{lagged}(\Delta X_t,\ \Delta Y_t) + \epsilon 1_t, \tag{3.8}$$

(3.9) $\Delta Y_t = \gamma_2 Z_{t-1} + \text{lagged}(\Delta X_t, \Delta Y_t) + \epsilon 2_t$,

where $Z_t = X_t - dY_t$, $\gamma_1 \neq 0$ or $\gamma_2 \neq 0$, and $\epsilon 1_t$, $\epsilon 2_t$ are white noise. An implication of cointegration and error correction models that is critical to the present study is the following: if two time series are cointegrated, there must be Granger causality in at least one direction, since one variable can help forecast the other. This result was established in Granger [1986] and Granger [1988a, 1988b].

The testing problem for cointegration is closely related to unit root tests. However, it is more complex because it involves estimated rather than observed time series. The testing procedure was developed in Engle and Granger [1987]. It starts by first establishing whether the individual series are I(0). This is done through the Dickey-Fuller test as discussed earlier. If the series are found to be I(1), the following "cointegration regression" is formed:

(3.10) $X_t = c + dY_t + e_t$

The residual e_t is then tested to see if it contains unit roots or not. If it does not, then it can be concluded that X_t and Y_t are cointegrated. Stock [1987] has shown that when X_t and Y_t are cointegrated, the OLS estimates of d are highly efficient and consistent. However, because e_t is not observed, the usual unit root tests, such as the Dickey-Fuller test, can not be used directly. Engle and Granger [1987] tried out several alternative testing procedures for unit roots. Because they found it to have the most stable critical values and good power properties, they recommended the use of the Augmented Dickey-Fuller test. This simply is a Dickey-Fuller unit root test that allows for more dynamics. Engle and Granger [1987] provided critical values for bivariate systems using 100 observations. Engle and Yoo [1987] generalized Engle and Granger's cointegration tests to allow for different sample sizes (up to 200 observations) and a larger number of variables (up to five variables). MacKinnon (1991) developed an algorithm that allows the computation of critical values for cointegration tests involving up to six variables and any number of observations.

Engle and Granger [1987] and Granger [1986] applied these cointegration tests to a number of US macroeconomic time series. They detected cointegration between national income and consumption; between short and long-term interest rates; and between non-durables, production and sales. They also found that the following variables were not cointegrated: wages and prices; durables, production and sales; money and prices; nominal GNP and M1 or M3 or total liquid assets. Many economists have since tested for cointegration in a variety of economic time series. Among them, Hall [1986] (wages, prices, average weekly hours worked, aggregate productivity and unemployment rate in the United Kingdom); Campbell [1987] (consumption and income); Corbae and Ouliaris [1987] (nominal exchange rates and relative prices); and Campbell and Shiller [1987] (dividends and share prices).

Once a system has been established to be cointegrated, an error correction representation can be used to make it stationary. Following Engle and Granger [1987], this error correction representation is developed in two steps. First, the parameters of the cointegrating regression are estimated. Then, these parameters are used in the error correction representation. Engle and Granger [1987] show that single equation OLS estimation of the cointegrating regression and the error correction model is consistent and efficient. More details on the development and estimation of the error correction representation will be given in Chapter V.

C. Stationarity and Granger Causality

The recent findings on the stationary nature of economic time series and the theory of cointegration facilitate the explanation and the reconciliation of the contradictory results of the various studies of money-income causality reported in Chapter II. One consequence of this research is an extension to VAR models of the long recognized fact that regressions containing stochastically trending variables may lead to spurious correlations (Granger and Newbold [1974]).

Sims, Stock and Watson [1990] show that in the presence of stochastic trends the asymptotic distribution theory may not be valid to interpret F-tests. An implication of this finding is that causality tests performed on regressions involving non-differenced series will typically have nonstandard distributions. Empirical substantiation of Sims, Stock and Watson's theoretical results is provided by Ohanian [1988] and Christiano and Ljungqvist [1987]. Ohanian [1988] develops a Monte Carlo experiment with a VAR including money, output, prices, interest rates, and an artificially generated independent random walk. He reports a significant rightward shift in the distribution of the F-statistic under the null of no causality. Christiano and Ljungqvist [1987] find similar results using a bivariate model of money and income.

The literature on cointegration and error correction models has shown that even those studies that used differenced data may suffer from misspecified models. As Granger (1988b) suggests, it appears, therefore, that many of the results of causality studies come from spurious regressions and should be reconsidered.

Stock and Watson [1989] have recently incorporated the new advances in time series analysis in an effort to explain the contradictory results on US money-income causality. Taking into account the orders of integration and co-integration of the variables and the presence (or absence) of polynomial time trends, they ran causality tests for US money and income using different model specifications: bivariate (money and income), trivariate (prices added) and four-variable (interest rates added). They employed monthly data over the sample period 1960:2 through 1985:12. Their main result is that, although money growth does not Granger cause income growth, the deviation of money growth from a linear trend does. They obtained this result for the bivariate as well as the multivariate specifications. Stock and Watson suggest that the contradictory results of earlier money-income causality studies come from the incorrect use of asymptotic distribution theory to analyze level regressions, and the failure of the researchers to focus on the non-deterministic components of money growth.

The econometric advances described in this chapter provide criteria to deal with the detrending problem that was, until recently, a major source of erroneous results in money-income causality testing. A focus on the trend properties of the data, and the use of the appropriate asymptotic theory would give more credibility to Granger causality studies.

CHAPTER IV

MONEY-INCOME CAUSALITY IN OPEN ECONOMIES

To date, the investigations of money-income causality that incorporate the advances in time series analysis presented in the previous chapter have been confined to the US, and to a closed economy framework. Obvious benefit can be gained by extending this research to an open economy framework and to other countries. As Granger (1969) implies, the causal structure defined from a subprocess of a multidimensional system does not allow for conclusions to be drawn about the causal structure of the larger system. If the higher-dimensional system contains relevant information beyond what is included in the subsystem, then the causality results from the subsystem may be spurious. Granger causality (or noncausality) in a subprocess may be due, for example, to an omitted variable (Lutkepohl [1982]). The recent studies of money-income causality have examined a subsystem (models with domestic variables only), and may have omitted important influences on the relationship between US money and US income. There are substantial differences in the operation of an economy when international influences are taken into account as compared to when they are not. This can be seen by contrasting the money supply process in an open economy to that in a closed one. In a closed economy, given certain assumptions about the preferences and behavior of banks and individuals, the monetary authority could completely determine the money supply. This is not the case for an open economy operating under a fixed exchange rate regime. In such an economy, the Central Bank is committed to maintaining the exchange rate of its currency within a prescribed range. It does this by buying and selling foreign exchange reserves on demand, thereby allowing international transactions of domestic and foreign residents to influence its holdings of international reserves, and thus its money supply. This means that under a regime of fixed exchange rates, the domestic money supply is partly determined by foreign factors. It is, therefore, entirely plausible that the relationship between domestic money supply and domestic income may be significantly different in an open economy than from that in a closed economy. What are the principal international factors that may have an influence on a given economy's money supply and aggregate income? A brief overview of open economy macroeconomics may help us answer this question.

A. Standard Open-Economy Macroeconomic Theory

The foundation of open economy macroeconomics was laid down by Robert Mundell and Marcus Fleming in the 1960's (Mundell [1968], Fleming [1962]). The Mundell-Fleming model is still the dominant paradigm in international economics. The following exposition is drawn from this model as presented by Dornbusch [1980]. An open economy functions differently according to whether it operates under a regime of fixed exchange rates or a regime of flexible exchange rates. Under a fixed exchange rate regime the Central Bank is required to preserve the value of its currency within a given range. Under a flexible exchange rate regime, on the other hand, the Central Bank can let market forces establish the exchange rate of its currency. The relative size of an economy can also be an important factor in the relationship between money and income. The following simplified theoretical exposition attempts to depict the relationship between domestic money and domestic income under alternative exchange rate regimes and relative economic sizes.

1. Fixed Exchange Rate Regime: Small Economy Case:

Let us first consider a small economy operating under a fixed exchange rate regime[10]. This economy is small in the sense that it has no noticeable influence on the world rate of interest nor on foreign incomes. Let us also assume that there is perfect international capital mobility[11]. In this economy, the demand for money is:

$$Md = L(r,Y) \tag{4.1}$$

with $\partial L/\partial r < 0$,

$\partial L/\partial Y > 0.$

L represents real balances, r is the interest rate, and Y is real income. An increase in real income raises the demand for real balances, while an increase in the rate of interest has the opposite effect.

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[10] The fixed exchange rate regime was instituted at the International Monetary Conference that was held in Bretton Woods, New Hampshire in 1944 by the major industrial countries. These countries agreed to keep the exchange rate of currencies within a prescribed range, and to make changes only in cases of fundamental disequilibrium. The rationale was that fixed exchange rates would encourage international trade by minimizing uncertainty.

[11] Perfect capital mobility requires perfect substitution between domestic and foreign interest-bearing assets, and instantaneous portfolio adjustment.

The supply of money is equal to net foreign assets F and domestic credit D:

(4.2) $$Ms = F + D.$$

Monetary equilibrium in this economy is reached when the supply of money equates the demand for money:

(4.3) $$F + D = L(r, Y)$$

Equilibrium income in this economy is determined as follows:

(4.4) $$Y = E(r, Y) + T(Y, Y_f, p)$$

with $\partial E/\partial r < 0$

$\partial E/\partial Y > 0$

$\partial T/\partial Y < 0$

$\partial T/\partial Y_f > 0$

$\partial T/\partial p > 0.$

E is aggregate spending by domestic residents, T is the trade balance (or net exports), Y_f is foreign income and p represents relative prices. This small economy is in equilibrium when both the money market and the goods market are in equilibrium. Given the assumption of perfect capital mobility, the equilibrium rate of interest for this small economy is equal to the world rate of interest.

Let us now assume that a fiscal expansion occurs. It raises aggregate demand and, therefore, output. The magnitude of the increase in output depends on the marginal propensity to save and the marginal propensity to import. The increased output stimulates the transactions demand for money. There ensues an upward pressure on the domestic interest rate, followed by an inflow of foreign capital. To prevent its currency from appreciating, the Central Bank intervenes by buying foreign currencies and creating domestic money until, once again, the money supply is equal to the money demand. This scenario shows clearly that for a small economy under a fixed exchange rate regime income causes money.

Next, let us consider a monetary expansion. An expansion of domestic credit puts a downward pressure on the domestic rate of interest. Given that the world rate of interest is unchanged, there is now a negative differential between the domestic and the world rates of interest. This causes an outflow of capital and a loss of reserves which continue until the initial rate of interest is reestablished. Equilibrium in the money market is attained when the money stock returns to its previous level, with the lost reserves offsetting the credit expansion. A small open economy with perfect capital mobility and operating under a fixed exchange rate regime, therefore, has no independent monetary policy. In such an economy, the direction of causality can only be from income to the money supply.

2. Fixed Exchange Rate Regime: Large Economy Case:

A large economy is an economy that has an impact on the world rate of interest and on foreign incomes. The demand for money in this economy is as in Equation (4.1).

$$Md = L(r,Y) \tag{4.1}$$

Its money supply is equal to the world money stock less foreign money demand:

$$Ms = D+D_f+F_w - L_f(r,Y_f) \tag{4.5}$$

where D is the domestic credit, D_f is foreign credit, F_w is the world reserve stock, L_f is the foreign money demand, r is the world rate of interest, and Y_f is foreign income. Equilibrium in the domestic and foreign money markets requires that the demand for money be equal to the supply of money:

$$D+D_f+F_w - L_f(r,Y_f) = L(r,Y) \tag{4.6}$$

As for the small country case, equilibrium in the domestic goods market is given by Equation (4.4):

$$(4.4) \qquad Y = E(r,Y) + T(Y,Y_f,p)$$

However, now domestic income can influence foreign income through the trade balance of foreign countries. An increase in domestic income increases domestic imports, thus raising the trade balance of other countries and, therefore, their equilibrium income.

An expansion of domestic credit decreases the domestic rate of interest, thus provoking a reserve loss. At the same time, however, the expanded domestic credit causes a world excess supply of money which puts downward pressure on the world rate of interest. The equilibrium world (and domestic) rate of interest eventually settles at a level lower than before the domestic monetary expansion. Thus, reserve loss does not completely offset the monetary expansion[12]. Because of the lower interest rate, equilibrium domestic income and foreign income are now higher. In this economy, then, money supply does cause income (through its effects on the interest

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[12] The extent to which the monetary expansion is offset by reserve losses is a function of the relative size of the domestic economy and of the domestic and foreign money demand elasticities. The larger the domestic economy, and/or the larger the domestic money demand elasticity, the smaller the offsetting effect of reserve losses.

rate). In addition, as is clear from Equation (4.6), income does cause money in such an economy. In conclusion, then, in a large economy under a fixed exchange rate regime and having perfect capital mobility, there is a feedback relationship between money and income: money causes income and income causes money.

3. Flexible Exchange Rate Regime: Small Economy Case:

In a regime of flexible exchange rates, the Central Bank is not obligated to maintain the value of its currency within a given range. Instead, it can let market forces determine the exchange rate. For a small economy, monetary equilibrium is achieved when the real money stock is equal to the demand for real money balances:

$$(4.7) \qquad Ms = L(r,Y)$$

The equilibrium income is a function of the real exchange rate e, the interest rate r, and real foreign income Y_f:

$$(4.8) \qquad Y = y(e,r,Y_f)$$

with $\partial y/\partial e < 0$

$\partial y/\partial r < 0$

$$\partial y/\partial Y_f > 0.$$

A real depreciation increases demand for domestic goods, and therefore real domestic income. A rise in real foreign income has the same effect. A higher interest rate, on the other hand, leads to a decreased demand for domestic goods and, therefore, a lower real domestic income. Because of its small size, the domestic economy takes the world rate of interest as given and has no noticeable impact on it. Now let us assume that a monetary expansion takes place. Initially, this leads to a drop in the interest rate and a rise in income. Given that the domestic rate of interest is below the world rate, capital starts to flow out of the country, resulting in a balance of payments deficit and eventually an exchange rate depreciation. This depreciation stimulates demand for domestic goods, further increasing domestic income. The depreciation will continue, as will the rise in domestic income, until the domestic rate of interest returns to the world level. At this level, monetary equilibrium is restored. In this scenario, an increase in the domestic money supply has caused domestic income to rise through exchange rate depreciation and the resulting improvement in the trade balance. Therefore, money causes income in a small open economy under a flexible exchange rate regime. This is the opposite of the fixed exchange rate regime case.

A fiscal expansion has different results. A fiscal expansion initially causes domestic income and domestic interest rate to rise. A capital inflow ensues, leading to exchange appreciation and a decline in domestic income. The exchange appreciation and the income drop continue until income and the interest rate return to their original levels. The money supply is also the original money supply. Therefore, in a small open economy with flexible exchange rates, income does not cause money.

4. Flexible Exchange Rate Regime: Large Economy Case:

The domestic goods and market equilibria are similar to the small country case. However, in this case, the domestic economy has a significant influence on the world rate of interest and the world income. The equilibrium conditions in the rest of the world are analogous to those of the domestic economy. The money market equilibrium for the rest of the world is:

$$Ms_f = L_f(r, Y_f) \tag{4.9}$$

The goods market equilibrium for the rest of the world is:

$$Y_f = y_f(e, r, Y) \tag{4.10}$$

with $\partial y_f/\partial e > 0$

$\partial y_f/\partial r < 0$

$\partial y_f/\partial y > 0.$

A real depreciation of the domestic currency decreases demand for foreign goods, and therefore real foreign income. A rise in real domestic income increases foreign income. The interest rate r, which is the same across all countries, negatively impacts foreign income.

Suppose there is now a monetary expansion in the domestic economy. The domestic rate of interest declines, causing a depreciation of the domestic currency and a rise in domestic income. The opposite happens in the rest of the world. Given an unchanged money stock in the rest of the world, a reduced rate of interest, and an appreciation of foreign currencies relative to the domestic currency, foreign income declines to keep the foreign money market in equilibrium. Hence, in a large country with flexible exchange rates, domestic money causes domestic income. In addition, domestic money affects foreign income.

Finally, let us consider a fiscal expansion in this large domestic economy. Both domestic and foreign (through the foreign trade multiplier) incomes increase. The world interest rate must rise to maintain monetary equilibrium. The end result is higher domestic and foreign incomes, a higher world rate of interest, and unchanged domestic and foreign money stocks. Thus, in a large economy with flexible exchange rates, domestic income does not cause domestic money. However, domestic income has an impact on foreign income.

As pointed out in chapter II, time series analysis is largely atheoretical. Nevertheless, economic theory may assist in the selection of the variables to be included in time series models. The above theoretical exposition suggests that some international factors are relevant in a study of the relationship between domestic money and domestic income. These factors are:

i) the exchange rate regime;
ii) the relative economic size of the domestic economy;
iii) the world income;
iv) the world money supply.

Besides the Mundell-Fleming Model, there is other evidence supporting the argument that the above factors may be important in a study of the relationship between domestic money and domestic income. Some of this evidence is presented next.

B. Further Evidence

1. International Currency Substitution:

The argument that the world money supply may be important to the relationship between domestic money and domestic income has been bolstered by several studies. The Mundell-Fleming model implies that under a fixed exchange rate regime foreign monetary shocks are readily transmitted to the domestic economy, whereas in a world of flexible exchange rates such monetary disturbances are not transmitted internationally. However, Miles [1978a, 1978b, 1981], McKinnon [1981, 1982], McKinnon and Tan [1983, 1984], and others have argued that in the presence of international currency substitution, independent monetary policy may be unattainable even with a regime of perfectly flexible exchange rates. It has traditionally been assumed that each country's money is held only by its own residents, ignoring the possibility that foreign currency is a substitute in demand for domestic currency. Miles, McKinnon and others, however, point out that for various reasons, some individuals, multinational corporations, speculators and Central Banks do hold both domestic and foreign currencies. The composition of this diversified portfolio of currencies changes in response to changes in the relative opportunity cost of holding foreign currency balances, thus leading to changes in relative money demands. This phenomenon, commonly referred to as international currency substitution, allows foreign monetary shocks to be transmitted (via money demand) to the domestic economy even with a flexible exchange rate regime. This fact lead McKinnon [1982] to conclude, that the world money supply was a better predictor of domestic economic activity than domestic money growth alone.

The concept of international currency substitution has generated a rich debate centered principally around its empirical prevalence and its implications for monetary and exchange rate policy (see, for example, Batten and Hafer [1985]; Boyer [1978]; Brittain [1981]; Burdo [1982]; Cox and Parkin [1988]); Laney, Radcliffe, and Willett [1984]; Marquez [1985]; McKinnon, Radcliffe, Tan, Warga, and Willett [1984]; Radcliffe, Warga, and Willett [1984, 1985]; Spinelli [1983]. Though the extent to which it is prevalent is still clouded in controversy, international currency substitution has nevertheless strengthened the view that domestic economies may be very sensitive to outside monetary shocks.

2. Effects of Exchange Rate Changes:

The results of some empirical studies reinforce the argument that exchange rate changes and world income may have a significant impact on the relationship between domestic money and domestic income. A study by Fair [1982] provides quantitative estimates of the impact of exchange rate changes on various economic variables in a number of countries. Table 1 below reproduces the effect of a sustained 10 percent depreciation of the German, British and Japanese exchange rates on real GNP and money supply.

Table 4.1 Impact of a sustained 10 percent depreciation on real GNP and Money Supply (in percentage change, initial change in first quarter 1976).

Country	Real GNP		Money Supply	
	2	6	2	6
Germany	0.72	0.20	-0.07	0.26
Japan	0.30	0.98	0.13	0.73
UK	0.62	-0.15	0.39	1.24

Source: Fair [1982], pp. 524, 526, 528.

From Table 4.1, we can see that a sustained 10 percent depreciation of the exchange rate leads to almost a 1 percent increase in Japanese real GNP (after six quarters) and a 1.24 percent increase in the UK money supply (after six quarters). Though these results are only indicative, they still suggest that exchange rate changes may have sizable effects on at least some countries' real GNP and money supply.

3. Spillover Effects:

Table 4.2 below shows the results from an OECD study of the spillover effects of aggregate demand disturbances for the major OECD countries. In the first column are the countries originating a 1 percent increase in autonomous spending. In the first row are the economies affected by this disturbance.

Table 4.2 Spillover effects of aggregate demand disturbances (in percentage).

Country	Canada	Germany	Japan	US
Canada	1.27	0.03	0.03	0.06
Germany	0.10	1.25	0.10	0.05
Japan	0.06	0.05	1.26	0.04
US	0.68	0.23	0.25	1.47
OECD	2.32	2.38	1.84	1.81

Source: OECD, Economic Outlook, Occasional Studies, Paris, 1979.

From this table, we see that spillover effects can be sizable. For example, a 1 percent increase in US aggregate demand leads to a 0.68 percent rise in Canadian income. Moreover, when there is a joint expansion by a group of countries, the impact on individual economies can be very important. A 1 percent increase in OECD aggregate demand leads to very substantial increases in individual incomes: from 1.81 percent for the United States to a 2.38 percent for Germany.

Another study by DeRosa and Smeal [1985] comes to similar conclusions. They find that a 1 percent expansion by any of the major industrial countries will lead to increased economic growth in the other industrial countries, the US and Germany having the greatest influence on other countries. For example, a 1 percent expansion in the US Real GDP may lead to a 0.25 percent increase in Belgium's Real GDP and a 0.21 percent increase in the UK's Real GDP within one year. Similarly, a 1 percent expansion in the German Real GDP may lead to a 0.57 percent increase in Belgium's Real GDP and an 0.18 percent increase in the UK's Real GDP within one year. Simulations from the large world simulation models such as DESMOS, METEOR and LINK all reveal some level of interdependence among the industrialized economies (see, for example, Deardorff and Stern [1977, 1979]; and Fair [1979]).

The theoretical and empirical evidence presented in this section strongly supports the argument that international factors, particularly the exchange rate regime, the relative economic size of the domestic economy, the world income, and the world money supply, may have an important influence on the relationship between domestic money and domestic income of a given economy. Money-income causality studies conducted within a closed-economy framework are, therefore, likely to produce spurious causality results. As mentioned earlier, the studies that have taken into account the new econometric progresses presented in Chapter III did not include any international factors. Open-economy investigations of money-income causality have been produced in the past. These studies, however, did not benefit from the recent econometric advances and, therefore, they were subject to the same problems as the closed-economy studies surveyed in Chapter II. The following section reviews these studies.

C. Money-Income Causality in Open Economies: Review of the Literature

Many of the researchers who were stimulated by Sims' work to investigate money-income causality in various countries attempted to incorporate open-economy considerations. The most important open-economy factor that most studies recognized was the exchange rate regime. Taking explicit account of the exchange rate regime, Sarlo [1979] reexamined the evidence on money-income causality for Canada. For the fixed exchange rate period (1962II-1970I) he found evidence of unidirectional causality between Canadian money and Canadian income. However, for the flexible exchange rate regime (1952I-1961II), he found no evidence of causality either way. This lead him to reject the earlier causality results for Canada by Barth and Bennett [1974], DyReyes [1974], and Sharpe and Miller [1975]. He attributed their disparate results to their failure to take into account the exchange rate regime.

Mixon, Pratt, and Wallace [1980] investigated the money-income causality for the United Kingdom under both exchange rate regimes. For both the fixed exchange rate period (1963I-1970IV) and the flexible exchange rate period (1974IV-1977III), they concluded on a feedback relationship between UK income and UK money. This conclusion contradicted both Williams, Goodhart and Gowland's [1976] and Mills and Wood's [1978] assertions that the money-income causality results for the United Kingdom would be sensitive to the exchange rate regime. It also disagreed with Cuddington's [1981] finding of a unidirectional causality running from UK income to UK money over the fixed exchange rate regime. For Japan, the exchange rate regime was found to be an important element in the relationship between money and income. Komura [1982] detected a feedback relationship over the fixed exchange rate period (1955I-1964IV) for Japan. For the flexible exchange rate regime (1971II-1980IV), however, he found a unidirectional causality from income to money.

Other open-economy factors that some studies took into account were foreign (i.e., US) money supply and income. Sheehan [1983] added the US money supply as an explanatory variable to the bivariate models of domestic income and domestic money for six countries (Australia, Canada, Germany, Italy, Japan, and the United Kingdom). He found unidirectional causality from income to money in Italy, Japan, and the United Kingdom; unilateral causality from money to income in Germany; bilateral causality in Australia; and no causality in Canada[13]. He also found that the US money supply was an important element in the relationship between domestic money and domestic income in most of these countries: the US money supply Granger-caused Australian and German money supplies, and Italian, Japanese and British incomes. Sheehan's domestic money-income causality results were at odds with DyReyes, Starleaf, and Wallace's [1980] for four out of five countries. Sheehan suggested DyReyes, Starleaf, and Wallace's results were misspecified because they excluded an important variable in their models (US money supply).

Mixon, Pratt, and Wallace [1979], and Cuddington [1981] studied the impact of US variables on UK income and money. Mixon, Pratt, and Wallace's conclusion was that US money supply Granger-caused UK income over the flexible exchange rate period, but not over the fixed exchange rate period. Cuddington found that over the fixed exchange rate period, US money supply Granger-caused UK money but not UK income; and US income Granger-caused UK income.

The foregoing survey suggests that for the most part, the exchange rate regime and foreign influences are important elements in a study of the direction of causality between domestic money and domestic income. Some of the divergent results of the studies reviewed in this section and in Chapter

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[13] These results obtained with M1 as the money supply variable. He found somewhat different results when he used M2.

II are caused by the failure of the closed-economy studies to take into account important factors in the relationship between domestic money and domestic income. Nevertheless, the studies reviewed in this section suffer from some of the same problems as those in Chapter II: inappropriate detrending, ad-hoc lag-length selection, various testing procedures. For example, Mixon, Pratt, and Wallace [1980] wrote: "Williams, Goodhart, and Gowland first-difference the variables to satisfy the covariance-stationarity requirement. Equivalently, we allow a linear time trend variable,..." It was shown clearly in Chapter III that first-differencing and linear regression were not equivalent[14], and that failure to use the appropriate detrending procedure would likely produce spurious results. Another example is provided by Komura [1982] and Ram [1984]. Ram replicated Komura's study for Japan using the same data and sample periods, but used the Granger-Sargent test procedure instead of the Sims procedure employed by Komura. His results pointed to a unidirectional causality from money to income over the fixed exchange period, and no clear evidence of causality over the flexible exchange rate period. Both of these results contradicted Komura's.

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[14] See also Kang [1985].

CHAPTER V

METHODOLOGY

In this chapter, the general methodology for carrying out the Granger causality tests is presented. This chapter is divided into three sections: trend characterization of the data, lag length selection, and Granger causality tests.

A. Trend Characterization of the Data

In Chapter II and III we saw that the results of Granger causality tests were critically sensitive to the trend characteristics, both deterministic and stochastic, of the time series under consideration. This section describes the methodology followed to determine the trend properties of the series used in this study.

1. Unit Root Tests:

To ascertain the stochastic-stationarity of each individual series, unit root tests are performed. The following regression is formed:

$$(5.1) \qquad \Delta X_t = \alpha_0 + \alpha_1 t + \beta X_{t-1} + \Sigma^p{}_{j=1}\ \delta_j \Delta X_{t-j} + e_t$$

where $\Delta = (1-L)$.

This is the Augmented Dickey-Fuller (ADF) unit root test. As discussed in Chapter III, this is simply a Dickey-Fuller test that incorporates a number of lagged first differences. The use of more dynamics is to secure an approximate white noise residual in the ADF regression. Therefore, p is chosen large enough to insure this. Regression (5.1) is run using ordinary least squares.

The null hypothesis is:

H_0: X_t contains a unit root.

The test-statistic is:

(estimated β) / (calculated standard error).

The decision rule is:

reject H_0 if estimated β is negative and significantly different from zero:

if (τ calculated) < 0 and

$| \tau \text{ calculated} | > | \tau \text{ critical} |$ ==> reject H_0

(i.e., no presence of a unit root).

The critical values of the t-statistic are computed using MacKinnon's (1991) algorithm:

$$\tau\text{-critical} = \beta_\infty + \beta_1/T + \beta_2/T^2$$

where (for 5 percent significance level):

$\beta_\infty = -3.4126$

$\beta_1 = -4.039$

$\beta_2 = -17.83$

and T is the sample size.

2. Deterministic Trends:

If a series is found to be I(1), its deterministic trends are identified by regressing the first difference of the series against a constant, time and its own lags. The number of lags should be large enough to obtain correct standard errors. A standard t-test is performed on the coefficient of time. If significant, it can be concluded that the series in levels is characterized by a unit root and a quadratic time trend. Its difference, however, will be stochastic-stationary and will have a linear time trend. For a series with non-significant time trend in the above regression, the time trend is dropped and the regression is reestimated. If the constant is significant, this is an indication that a constant should be included in the difference specification of the series. This is the procedure Stock and Watson [1989] followed to identify the deterministic trend properties of their series.

3. Cointegration Tests:

The cointegration testing procedure I will use is the Engle-Granger Cointegration (EG) test as described in Engle and Granger [1987] and extended in Engle and Yoo [1987]. First, it is determined that the series under consideration are I(1). This is done through the Augmented Dickey-Fuller test as shown above. Then a cointegration regression is formed:

$$X_t = c + bY_t + Z_t \tag{5.2}$$

where c is a constant, b is a vector of coefficients, Y_t a vector of time series, and Z_t is the residual. As mentioned in Chapter III, OLS gives very efficient and consistent estimates of the coefficients b. Next, the Augmented Dickey-Fuller test is run on the residual Z_t.

(5.3) $$\Delta Z_t = \alpha + \beta Z_{t-1} + \Sigma^{p}_{j=1}\, \delta_j \Delta Z_{t-j} + e_t$$

The null hypothesis is:

H_0: Z_t contains a unit root
(i.e., X_t and Y_t are not cointegrated).

The test statistic is:

(estimated β) / (calculated standard error).

The decision rule is:

reject H_0 if estimated β is negative and significantly different from zero:

if (τ calculated) < 0 and
$|\tau \text{ calculated}| > |\tau \text{ critical}|$ ==> reject H_0
(i.e., X_t and Y_t are cointegrated).

As for the unit root tests, the critical values for the cointegration tests are computed using the MacKinnon (1991) algorithm for the appropriate number of variables.

B. Lag Length Selection

Chapter II showed that the results of Granger causality tests were sensitive to the lag structure used. For this reason, an optimal procedure of lag length selection is needed. Such a procedure is provided by Hsiao [1981]. Hsiao's is a sequential procedure that allows the construction of parsimonious models without imposing a priori constraints. It is based on Akaike's [1969a, 1969b] final prediction error (FPE). The FPE is defined as the asymptotic mean square prediction error. For a bivariate system, the FPE is calculated as:

$$FPE(r,s) = [(n + r + s)/(n - r - s)] \cdot [SSE(r,s)/n] \tag{5.4}$$

where r, s are the lag lengths of the two variables, n is the number of observations, and SSE is the sum of squared errors.

As for most model selection criteria, the FPE balances the risk due to the bias associated with a parsimonious parametrization (low lag order) and the risk due to the inefficiency associated with overparametrization (high lag order). The FPE tends to favor unbiasedness over inefficiency.

Given a bivariate model composed of X_t and Y_t, Hsiao's procedure is performed as follows:

1. Determine the optimal order of the first variable, say X_t. This is done by first treating X_t as a univariate autoregressive process[15]. The FPE of X_t is then computed using lags varying from 1 to an a priori specified maximum lag R. The lag with the smallest FPE is selected as the optimal lag order of X_t.

2. Add the other variable to the above model. The lag order of X_t is the one defined in step 1. Varying the maximum order of lags of Y_t from 1 to a given number S, the FPE of the model is computed. The order that produces the smallest FPE is chosen as the optimal order of Y_t.

3. Repeat steps 1-2 starting with Y_t.

This procedure can easily be extended to models with several variables[16]. Hsiao's procedure has been used by a number of researchers because they have found it to perform

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[15] In this univariate process, the value of s in Equation (5.4) would be set equal to zero.

[16] Hsiao asserts that a minimum FPE from step 2 that is less than the minimum FPE from step 1 represents evidence of Granger causality from the second variable to the first variable. More generally, he implies that his procedure is a test of Granger causality: if FPE(X,Y) < FPE(X) then Y Granger-causes X. This is true, but the FPE criterion uses higher than conventional significance levels. Therefore, there is still need to apply the statistical Granger causality tests to obtain results at the conventional significance levels (see Thornton and Batten [1985]).

well in model selection relative to the alternatives (see, for example, Thornton and Batten [1985], Falls and Hill [1985], and Serlitis [1988]). For this reason, this procedure will be relied upon to select the lag structure of the models used for Granger causality testing.

C. Granger Causality Tests

Equations (5.5) and (5.6) represent the general model specifications used in the money-income Granger causality tests.

$$\Delta Y_t = a_0 + a_1 t + h\ Z_{t-1} + b\ m(L)\ \Delta M_{t-1} + b\ y(L)\ \Delta Y_{t-1} + b\ x(L)\ X_{t-1} + e_t \tag{5.5}$$

$$\Delta M_t = c_0 + a_2 t + k\ Z_{t-1} + d\ m(L)\ \Delta M_{t-1} + d\ y(L)\ \Delta Y_{t-1} + d\ x(L)\ X_{t-1} + u_t \tag{5.6}$$

where Y_t is income, M_t is money supply, X_t is a vector of other relevant variables, Z_t is the error correction term, and e_t and u_t are white noise processes.

The procedures outlined above help in determining the specific models to be tested. The outcomes of the unit root tests determine if and how many times each variable is to be differenced. The tests for deterministic trends ascertain what deterministic trends and constants to include. The cointegration tests establish whether an error correction term should be part of the model. Finally, Hsiao's procedure helps determine the lag structure of the models.

To test whether money Granger-causes income, an F-test is run on Equation (5.5) (in its specific version). The null hypothesis is that bm(L)=0. Given that the variables in this equation are now stationary, standard test statistics can be used. If this hypothesis is rejected at a given significance level, then it can be concluded that money does Granger-cause income for the sample period under consideration. To test whether income Granger-causes money, the test procedure just described is repeated using Equation (5.6) and the null hypothesis that dy(L)=0.

Money-income causality is examined for three countries. These countries have been chosen on the basis of their economic size and their openness, as measured by the foreign trade over Gross Domestic Product ratio[17]. These countries are: United States (large economy), Canada (medium-sized economy, fairly open economy), and Netherlands (small, open economy).

Table 5.1 GDP and foreign trade: United States, Canada, and Netherlands.

	United States	Canada	Netherlands
GDP[1]	$5,423.4	$583.0	$277.0
GDP[2]	5,423.4	671.6	508.3
Imports[2]	608.4	166.9	262.1
Exports[2]	535.4	168.9	287.9
Ratio[3]	21.1%	50.0%	108.2%

Source: WEFA - World Economic Outlook, vol. 1, October 1991.

1. In US dollars, current prices, year=1990.
2. Local currency in billions, current prices, year=1990.
3. Ratio of imports plus exports over GDP.

For each of the these countries a series of models are built to test for both money-income causality and income-money causality.

<u>Model 1:</u> The first model incorporates only domestic variables that have been found in previous studies to belong in a model testing money-income causality. These variables are income, money supply, prices, and the interest rate.

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[17] Data availability also played an important role in the selection of these three countries.

Model 2: Domestic prices are added to Model 1.

Model 3: Short term interest rates are added to Model 2.

Model 4: An international variable (world money) is added to model 3.

Model 5: The other international variable (world income) is substituted for world money in Model 3.

Model 6: Both international variables are added to model 3.

These six sets of models are built and tested over three different sample periods:

i) full sample: 1960:1-1990:6;
ii) fixed exchange rate regime sample: 1960:1-1971:7[18], [19].
iii) flexible exchange rate regime sample: 1973:7-1990:6[20].

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[18] In August 1971 the United States cut the link between the dollar and gold. This marked the end of the Bretton Woods accords.

[19] Canada had a flexible exchange rate regime until 1961. For Canada, therefore, the fixed exchange rate regime sample is from 1962:1 to 1971:7. The fixed exchange rate regime in the Netherlands ended in May 1971 when it floated the guilder.

[20] The 1971 to 1973 period was a period of transition from fixed exchange rates to flexible exchange rates. It is, therefore, not included in either of the smaller samples.

D. Data and software

Monthly data of each variable are used. Most of the series were obtained from the OECD's Main Economic Indicators data base. Appendix A describes the domestic variables for all three countries. The world income is proxied by the aggregated OECD Industrial Production Index[21], while world money is represented by the IMF's World Money Supply M1 Index[22]. Following many of the earlier studies, all series except the interest rate are used in their logarithmic form. All regressions are run using the RATS software package.

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[21] This index includes all OECD member countries of Europe, Canada, United States, Australia, New Zealand, and Japan.

[22] The IMF's World Money Supply Index is not seasonally adjusted. Therefore, the Bureau of the Census X-11 procedure (in SAS) was applied to seasonally adjust it. This is the same procedure that was used to seasonally adjust the MEI series.

CHAPTER VI

RESULTS

This chapter presents the results of this project. The results for the United States (full sample) are given in extensive detail to illustrate the methodology followed. The results for the other sample periods and the other countries are presented more briefly.

A. United States

All tests are carried out over three different sample periods:

i) Full sample period: 1960:1 to 1990:6;
ii) Fixed exchange rate period: 1960:1 to 1971:7;
iii) Flexible exchange rate period: 1973:7 to 1990:6.

For each sample period, three sets of tests are performed:

i) Tests to determine the trend characterization of the data;

ii) Tests to define the optimal lag length of the various models; and finally

iii) Granger causality tests.

1. Full Sample: 1960:1 - 1990:6:

a. Trend characterization of the data.

i. Unit root tests. Tests for the presence of up to two unit roots and deterministic trends up to second order are performed for each of income y, money supply m, prices p, interest rates r, world income wy and world money supply wm. As was discussed in Chapter V, all series, except interest rates are used in logs. To test for the presence of a single unit root, the following regression is run:

$$(6.1) \qquad \Delta X_t = \alpha_0 + \alpha_1 t + \beta X_{t-1} + \Sigma^p{}_{j=1}\, \delta_j \Delta X_{t-j} + e_t$$

To test for the presence of two unit roots, regression (6.1) is rerun using first differences instead of levels, and second differences instead of first differences:

$$(6.2) \qquad \Delta^2 X_t = \alpha_0 + \alpha_1 t + \beta \Delta X_{t-1} + \Sigma^p{}_{j=1}\, \delta_j \Delta^2 X_{t-j} + e_t$$

Following Stock and Watson [1989], six lags of the differences of the series are used. Using 12 lags did not qualitatively alter the results. Table 6.A1.1 presents the results of the tests for the presence of one unit root (column 2), the presence of two unit roots (column 3), and the presence of time trends (column 5), and constants (column 6). Column 4 summarizes the number of unit roots detected in each series.

For income y, the t-statistic associated with ß in the test for one unit root is -3.409. The critical value is computed using MacKinnon's [1991] formula:

$$\tau\text{-critical} = \beta_\infty + \beta_1/T + \beta_2/T^2 \tag{6.3}$$

From Table 1 in MacKinnon [1991], page 13, for a 5% significance level:

$$\beta_\infty = -3.4126, \quad \beta_1 = -4.039, \text{ and } \quad \beta_2 = -17.83.$$

Given a sample size of 354,

$$\tau\text{-critical} = -3.4126 + (-4.039/354) + (-17.83/354^2) = -3.424$$

Since

$$| \tau\text{-calculated}=-3.409 | \quad < \quad | \tau\text{-critical}=-3.424 | \quad ,$$

the null hypothesis that income y contains one unit root cannot be rejected at the 5 percent significance level. For the test for two unit roots, the τ-calculated is -6.464. Since

$$| \tau\text{-calculated}=-6.464 | > | \tau\text{-critical}=-3.424 | ,$$

the null hypothesis that income y contains two unit roots is rejected at the 5 percent significance level. Therefore, over the sample period 1960:1 to 1990:6, US income contains only one unit root (Table 6.A1.1, column 4, row 2).

ii. Deterministic trends. Since y is I(1), its first difference is regressed against a constant, a time trend, and six of its own lags. The t-statistic associated with the coefficient of time is 2.956 (Table 6.A1.1, column 5). Using standard t-tests, it can be concluded that the time trend is significant at the 5 percent significance level. Income y in levels, therefore, is characterized by one unit root and a quadratic time trend. Its first difference, however, is stationary and has a linear time trend.

This procedure is repeated for each variable. The results are displayed in Table 6.A1.1. Over the sample period 1960:1 to 1990:6, US income y, money supply m, prices p, interest rates r, as well as world money wm and world income wy are well characterized as having one unit root each.

Income growth (the first difference of the logarithm of income), money growth, world income growth and world money growth all display evidence of deterministic trends. The first difference of interest rates has a significant drift, while inflation has neither a significant time trend nor a significant drift.

Table 6.A1.1 Tests for unit roots and time trends, United States, 1960:1 - 1990:6

Series	$\tau[X]$	$\tau[\Delta X]$	Number of Unit Roots	Trend	Constant
y	-3.409	-6.464	1	2.956	2.654
m	-2.317	-5.966	1	2.528	-0.531
p	-1.800	-3.686	1	1.618	0.603
r	-2.028	-9.538	1	1.441	2.348
wy	-2.628	-5.640	1	2.265	2.240
wm	-1.976	-5.397	1	2.640	2.568

Critical value: -3.424 (N=354, 5% significance level)

iii. Cointegration tests. Models including the above series will have at most as many unit roots as variables. If the series are cointegrated, (i.e., if they have common stochastic trends), the models will have fewer unit roots than variables. There are twelve models per sample period per country: six income models and six money models. These models range from two variables (domestic income and money supply only) to six variables (domestic income, money supply, prices and interest rates and world income and money supply). A cointegration test is conducted for each model. The Engle-Granger procedure described in Chapter V is used to perform the cointegration tests. To illustrate how this procedure was used, the test for cointegration between income y and money supply m is detailed. It has already been established above that both y and m are I(1). Therefore, a model composed of these two variables will have at most two unit roots.

However, if these series have stochastic trends in common, they will be cointegrated and, therefore, will have less than two unit roots. The following cointegration regression is run:

$$(6.4) \qquad y_t = a + bm_t$$

Then a unit root test similar to the one presented above is performed on the residual of (6.4). The τ-calculated is -3.281 (Table 6.A1.2, row 2, column 2). The critical value is computed using MacKinnon's [1991] formula (6.3). From MacKinnon [1991], page 13, Table 1 for a 5% significance level and two variables:

$$\beta_\infty = -3.3377, \quad \beta_1 = -5.967, \text{ and } \quad \beta_2 = -8.98.$$

Given the sample size of 354,

$$\tau\text{-critical} = -3.3377 + (-5.967/354) + (-8.98/354^2) = -3.355$$

Since

$$|\ \tau\text{-calculated}=-3.281\ | \quad < \quad |\ \tau\text{-critical}=-3.355\ | \quad ,$$

the null hypothesis that US income y and money supply m are not cointegrated cannot be rejected at the 5 percent significance level.

This procedure is repeated for all the other models and the cointegration results for the United States (full sample) are displayed in Tables 6.A1.2 and 6.A1.3. For all multivariate models, the tests fail to reject (at the 5 percent significance level) the null hypothesis that the series are not cointegrated.

Table 6.A1.2 Cointegration tests, United States, 1960:1 - 1990:6. Income models.

Model	$\tau[Z]$	Critical value	Cointegrated?
y,m	-3.281	-3.355	No
y,m,p	-3.219	-3.361	No
y,m,p,r	-2.491	-4.131	No
y,m,p,r,wy	-2.904	-4.457	No
y,m,p,r,wm	-1.259	-4.457	No
y,m,p,r,wy,wm	-2.787	-4.753	No

N=354, 5% significance level

Table 6.A1.3 Cointegration tests, United States, 1960:1 - 1990:6. Money models.

Model	$\tau[Z]$	Critical value	Cointegrated?
m,y	-2.372	-3.355	No
m,y,p	-1.175	-3.361	No
m,y,p,r	-1.547	-4.131	No
m,y,p,r,wy	-1.686	-4.457	No
m,y,p,r,wm	-1.942	-4.457	No
m,y,p,r,wm,wy	-1.983	-4.753	No

N=354, 5% significance level

To summarize the results in this section,

- .all series have one unit root;
- .no series are cointegrated.

These results suggest that first differences of the variables should be used in the Granger causality tests. Taking first differences of the series insures that none of the variables contains a unit root, and therefore the standard procedures of asymptotic inference can be used.

b. Lag length selection. The optimal lag length of each variable in each model is determined according to the procedure outlined in Chapter V. Because first differences of the variables will be used in the Granger causality tests, first differences are used in the FPE tests as well. For the income models, the optimal lag length of the variable Δy_t is defined first. This is done by treating Δy_t as a univariate autoregressive process (6.5) and computing the FPE of this process at lags varying from 1 to 24. The lag specification with the lowest FPE is selected as the optimal specification. For the income variable, the specification with 3 lags, with FPE equal to 62.034×10^{-6}, provides the lowest FPE (see Appendix B).

$$(6.5) \qquad \Delta y_t = \alpha + \beta t + \Sigma_{i=1}{}^{r} \Delta y_{t-i}, \qquad r = 1, \ldots, 24$$

Keeping the optimal lag specification (r=3), the money variable (in first differences), with lags varying from 1 to 24, is added to model (6.5). This becomes model (6.6).

$$(6.6) \qquad \Delta y_t = \gamma + \theta t + \Sigma_{i=1}{}^{3} \Delta y_{t-i} + \Sigma_{j=1}{}^{s} \Delta m_{t-j}, \quad s = 1, \ldots, 24$$

The FPE of this model is computed at each lag length. The lag length s, producing the lowest FPE, is taken as the optimal lag length of the money variable. The minimum FPE ($60.758\text{x}10^{-6}$) occurs at lag length s=4.

Prices, then interest rates, then world income and finally world money supply are added to model (6.6) and each time the FPEs are computed. Table 6.A1.4 displays the optimal lag length selection results for the income models. This procedure is also applied to the money supply models and the results are presented in Table 6.A1.5.

Table 6.A1.4 Optimal lag lengths, United States, 1960:1 - 1990:6. Income models.

Model	Minimum FPE ($x10^{-6}$)	Optimal lag length
y	62.034	3
y,m	60.758	4
y,m,p	59.555	5
y,m,p,r	59.549	1
y,m,p,r,wy	59.348	2
y,m,p,r,wm	59.863	1
y,m,p,r,wy,wm	59.606	2

Table 6.A1.5 Optimal lag lengths, United States, 1960:1 - 1990:6. Money models.

Model	Minimum FPE ($x10^{-6}$)	Optimal lag length
m	21.924	9
m,y	21.520	3
m,y,p	21.279	3
m,y,p,r	18.055	5
m,y,p,r,wm	18.112	1
m,y,p,r,wy	18.087	1
m,y,p,r,wm,wy	18.152	1

c. Granger causality tests. The results from the above sections are used to specify the various models used for the Granger causality tests. The income models are used to test whether money Granger-causes income, while the money models are utilized to test whether income Granger-causes money.

i. Income models. A set of six models (three including only domestic variables, models 1 through 3, and three incorporating both domestic and international variables, models 4 through 6) are formed on the basis of the above results. For each of these models, an F-test is run. The null hypothesis is

$$H_0: \Sigma_{j=1}{}^{4} \beta_{mj} = 0$$

The results of the F-tests for the income models are displayed in Tables 6.A1.6 and 6.A1.7. For model 1 (y,m), the calculated F-statistic is 3.953. The critical F-statistic for (4, 352) degrees of freedom is 2.37 at the 5 percent significance level. Given that

$$(\text{F-calculated}=3.953) > (\text{F-critical}=2.37)$$

the null hypothesis is rejected and it can be concluded that money does Granger-cause income in the bivariate (y,m) model. The same conclusion is reached for the other income models, though for models 3 (y,m,p,r), 5 (y,m,p,r,wm) and 6 (y,m,p,r,wy,wm), the significance level is 10 percent.

Model 1 (y,m):

(6.7) $$\Delta y_t = \gamma + \theta t + \Sigma_{i=1}{}^{3}\ \beta_{yi}\Delta y_{t-i} + \Sigma_{j=1}{}^{4}\ \beta_{mj}\Delta m_{t-j}$$

Model 2 (y,m,p):

(6.8) $$\Delta y_t = \gamma + \theta t + \Sigma_{i=1}{}^{3}\ \beta_{yi}\Delta y_{t-i} + \Sigma_{j=1}{}^{4}\ \beta_{mj}\Delta m_{t-j}$$

$$+ \Sigma_{k=1}{}^{5}\ \beta_{pk}\Delta p_{t-j}$$

Model 3 (y,m,p,r):

(6.9) $$\Delta y_t = \gamma + \theta t + \Sigma_{i=1}{}^{3}\ \beta_{yi}\Delta y_{t-i} + \Sigma_{j=1}{}^{4}\ \beta_{mj}\Delta m_{t-j}$$

$$+ \Sigma_{k=1}{}^{5}\ \beta_{pk}\Delta p_{t-k} + \beta_{r1}\Delta r_{t-1}$$

Model 4 (y,m,p,r,wy):

(6.10) $$\Delta y_t = \gamma + \theta t + \Sigma_{i=1}{}^{3}\ \beta_{yi}\Delta y_{t-i} + \Sigma_{j=1}{}^{4}\ \beta_{mj}\Delta m_{t-j}$$

$$+ \Sigma_{k=1}{}^{5}\ \beta_{pk}\Delta p_{t-k} + \Delta r_{t-1} + \Sigma_{l=1}{}^{2}\ \beta_{wyl}\Delta wy_{t-l}$$

<u>Model 5 (y,m,p,r,wm):</u>

$$(6.11) \qquad \Delta y_t = \gamma + \theta t + \Sigma_{i=1}{}^{3}\ \beta_{yi}\Delta y_{t-i} + \Sigma_{j=1}{}^{4}\ \beta_{mj}\Delta m_{t-j}$$

$$+ \Sigma_{k=1}{}^{5}\ \beta_{pk}\Delta p_{t-k} + \beta_{r1}\Delta r_{t-1} + \beta_{wm1}\Delta wm_{t-l}$$

<u>Model 6 (y,m,p,r,wy,wm):</u>

$$(6.12) \qquad \Delta y_t = \gamma + \theta t + \Sigma_{i=1}{}^{3}\ \beta_{yi}\Delta y_{t-i} + \Sigma_{j=1}{}^{4}\ \beta_{mj}\Delta m_{t-j}$$

$$+ \Sigma_{k=1}{}^{5}\ \beta_{pk}\Delta p_{t-k} + \beta_{r1}\Delta r_{t-1} + \Sigma_{l=1}{}^{2}\ \beta_{wyl}\Delta wy_{t-l}$$

$$+ \Sigma_{h=1}{}^{2}\ \beta_{wmh}\Delta wm_{t-h}$$

Table 6.A1.6 Granger causality tests, United States, 1960:1-1990:6. Income models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m	(4, 352)	3.953	Yes
y/m,p	(4, 346)	2.676	Yes
y/m,p,r	(4, 345)	2.360	No (Yes*)

Critical value: 2.37 (5% significance level)
1.94 (10% significance level)
*Significant at the 10% level.

Table 6.A1.7 Granger causality tests, United States, 1960:1-1990:6. Income models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m,p,r,wy	(4, 343)	2.447	Yes
y/m,p,r,wm	(4, 344)	2.347	No (Yes*)
y/m,p,r,wy,wm	(4, 341)	2.149	No (Yes*)

Critical value: 2.37 (5% significance level)
1.94 (10% significance level)
*Significant at the 10% level.

ii. Money models. The procedure used to test whether money Granger-causes income is followed to test the reverse causality (income Granger-causes money). The results are shown in Tables 6.A1.8 (domestic variables only), and 6.A1.9 (both domestic and international variables). Only in the bivariate model (m,y) and 3-variable model (m,y,p) is there evidence supporting a conclusion of Granger causality from income to money. No evidence of income to money causality is found in the other four models, not even at the 10 percent significance level.

Table 6.A1.8 Granger causality tests, United States, 1960:1-1990:6. Money models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y	(3, 342)	2.595	Yes
m/y,p	(3, 339)	3.008	Yes
m/y,p,r	(3, 334)	1.903	No

Critical value: 2.60 (5% significance level)
2.08 (10% significance level)

Table 6.A1.9 Granger causality tests, United States, 1960:1-1990:6. Money models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y,p,r,wy	(3, 333)	0.478	No
m/y,p,r,wm	(3, 333)	1.829	No
m/y,p,r,wm,wy	(3, 332)	0.470	No

Critical value: 2.60 (5% significance level)
2.08 (10% significance level)

2. Fixed Exchange Rate Regime: 1960:1 - 1971:7:

a. Trend characterization of the data. Table 6.A2.1 displays the results of the unit root and time trend tests for the United States for the fixed exchange rate period. These results suggest that, for the sample period 1960:1 to 1971:7, income has one unit root and a significant linear time trend; money supply has one unit root with no significant time trend or drift; prices have one unit root and a quadratic time trend; interest rates are stationary in levels; world income has one unit root and no significant time trend or drift; and world money has two unit roots.

Table 6.A2.1 Tests for unit roots and time trends, United States, 1960:1-1971:7.

Series	$\tau[X]$	$\tau[\Delta X]$	Number of Unit Roots	Trend	Constant
y	-0.375	-5.239	1	-0.248	3.337
m	-1.232	-4.126	1	1.508	-1.600
p	-1.107	-4.425	1	2.338	-2.302
r	-3.568	-4.629	0		
wy	-1.038	-4.339	1	1.007	1.871
wm	-1.833	-2.850	2	1.235	2.142

Critical value: -3.446 (N=127, 5% significance level)

Multivariate models containing the levels of income, money supply, prices, world income and the first difference of world money will have at most as many unit roots as variables. However, if these series are cointegrated, the number of unit roots in the models will be reduced. Tables 6.A2.2 and 6.A2.3 present the cointegration test results for the income models and money models, respectively. In these models, wm represents the first difference of world money. Since interest rate r is stationary in levels, it cannot have common stochastic trends with the other series and is thus left out of the cointegration tests. There is no evidence of cointegration among any of these series.

Table 6.A2.2 Cointegration tests, United States, 1960:1-1971:7. Income models.

Model	τ[Z]	Critical value	Cointegrated?
y,m	-0.967	-3.385	No
y,m,p	-2.255	-3.810	No
y,m,p,wy	-2.380	-4.186	No
y,m,p,wm	-2.111	-4.186	No
y,m,p,wy,wm	-2.302	-4.527	No

N=127, 5% significance level

Table 6.A2.3 Cointegration tests, United States, 1960:1 - 1971:7. Money models.

Model	τ[Z]	Critical value	Cointegrated?
m,y	0.135	-3.385	No
m,y,p	-2.754	-3.810	No
m,y,p,wy	-2.487	-4.186	No
m,y,p,wm	-2.654	-4.186	No
y,m,p,wm,wy	-2.754	-4.527	No

N=127, 5% significance level

To summarize the results of this section,

- .domestic income, money supply, prices and world income have one unit root each;
- .interest rates are stationary in levels;
- .world money has two unit roots;
- .no series are cointegrated.

These results suggest that first differences of domestic income, money supply and prices should be used in the Granger causality tests, while interest rates can be used in levels, and world money supply in second differences.

b. Lag length selection. The procedure described in Chapter V is followed in order to obtain the optimal lag length specifications. The results of this procedure are displayed in Table 6.A2.4 for the income models and Table 6.A2.5 for the money models.

Table 6.A2.4 Optimal lag lengths, United States, 1960:1-1971:7. Income models.

Model	Minimum FPE ($x10^{-6}$)	Optimal lag length
y	60.54	4
y,m	61.51	1
y,m,p	59.02	1
y,m,p,r	57.86	1
y,m,p,r,wy	58.25	2
y,m,p,r,wm	55.68	12
y,m,p,r,wy,wm	56.29	12

Table 6.A2.5. Optimal lag lengths, United States, 1960:1-1971:7. Money models.

Model	Minimum FPE ($x10^{-6}$)	Optimal lag length
m	10.116	3
m,y	9.414	1
m,y,p	9.141	5
m,y,p,r	8.816	3
m,y,p,r,wm	8.981	1
m,y,p,r,wy	8.819	4
m,y,p,r,wm,wy	8.897	4

c. Granger causality tests. The models used to test for Granger causality between income and money are built according to the outcomes of the above sections. The Granger causality tests results are presented in Tables 6.A2.6 and 6.A2.7 for the income models, and Tables 6.A2.8 and 6.A2.9 for the money models.

i. Income models.

Table 6.A2.6 Granger causality tests, United States, 1960:1-1971:7. Income models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m	(1, 128)	0.192	No
y/m,p	(1, 126)	0.666	No
y/m,p,r	(1, 125)	0.585	No

Critical value: 3.92 (5% significance level)
2.75 (10% significance level)

At the 5 percent (or 10 percent significance level), there is no evidence of Granger causality from money to income in any model with only domestic variables.

Table 6.A2.7 Granger causality tests, United States, 1960:1-1971:7. Income models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m,p,r,wy	(1, 123)	0.563	No
y/m,p,r,wm	(1, 104)	0.335	No
y/m,p,r,wy,wm	(1, 102)	0.373	No

Critical value: 3.92 (5% significance level)
2.75 (10% significance level)

The addition of international variables does not alter the conclusion of no Granger causality from money to income for the United States over the 1960:1 to 1971:7 sample period.

ii. Money models. From Table 6.A2.8, it can be seen that there is no evidence of Granger causality from money to income, not even at the 10 percent significance level, in all of the models with only domestic variables. As Table 6.A2.9 shows, adding international variables to domestic variables does not change this result.

Table 6.A2.8 Granger causality tests, United States, 1960:1-1971:7. Money models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y	(1, 130)	1.268	No
m/y,p	(1, 122)	1.845	No
m/y,p,r	(1, 119)	1.528	No

Critical value: 3.92 (5% significance level)
2.75 (10% significance level)

Table 6.A2.9 Granger causality tests, United States, 1960:1-
1960:1-1971:7. Money models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y,p,r,wy	(1, 115)	1.506	No
m/y,p,r,wm	(1, 118)	1.614	No
m/y,p,r,wm,wy	(1, 114)	1.428	No

Critical value: 3.92 (5% significance level)
2.75 (10% significance level)

3. Flexible Exchange Rate Regime: 1973:7 - 1990:6:

a. Trend characterization of the data. Table 6.A3.1 displays the results of the unit root and time trend tests for the United States for the flexible exchange rate period. From this table it can be seen that income, money supply, world income and world money supply each have one unit root and a quadratic time trend, while prices and interest rates each have one unit root and a linear time trend. Tables 6.A3.2 and 6.A3.3 show the cointegration tests results. The null of no cointegration is not rejected in any of the tests.

Table 6.A3.1 Tests for unit roots and time trends, United States, 1973:7-1990:6.

Series	$\tau[X]$	$\tau[\Delta X]$	Number of Unit Roots	Trend	Constant
y	-2.904	-4.570	1	2.889	0.440
m	-1.963	-4.344	1	1.985	0.794
p	-1.436	-3.478	1	0.330	2.587
r	-1.490	-7.171	1	-0.010	1.997
wy	-3.368	-4.330	1	3.371	0.323
wm	-2.373	-4.371	1	2.220	2.699

Critical value: -3.434 (N=194, 5% significance level)

Table 6.A3.2 Cointegration tests, United States, 1973:7 - 1990:6. Income models.

Model	$\tau[Z]$	Critical value	Cointegrated?
y,m	-2.562	-3.370	No
y,m,p	-2.543	-3.788	No
y,m,p,r	-2.359	-4.158	No
y,m,p,r,wy	-2.685	-4.491	No
y,m,p,r,wm	-2.488	-4.491	No
y,m,p,r,wy,wm	-3.357	-4.796	No

N=194, 5% significance level

Table 6.A3.3 Cointegration tests, United States, 1973:7-1990:6. Money models.

Model	$\tau[Z]$	Critical value	Cointegrated?
m,y	-2.651	-3.370	No
m,y,p	-1.971	-3.788	No
m,y,p,r	-1.970	-4.158	No
m,y,p,r,wy	-2.462	-4.491	No
m,y,p,r,wm	-1.389	-4.491	No
m,y,p,r,wm,wy	-1.186	-4.796	No

N=194, 5% significance level

To summarize the results of this section,

- .all series have one unit root;
- .no series are cointegrated.

These results suggest that all series should be used in first differences in the Granger causality tests.

b. length selection. Tables 6.A3.4 and 6.A3.5 display the results of the optimal lag length selection procedure. The optimal lag lengths determined in this section will serve to specify the models used for the Granger causality tests.

Table 6.A3.4 Optimal lag lengths, United States, 1973:7-1990:6. Income models.

Model	Minimum FPE ($x10^{-6}$)	Optimal lag length
y	53.615	3
y,m	62.140	4
y,m,p	46.006	3
y,m,p,r	46.285	1
y,m,p,r,wy	59.610	1
y,m,p,r,wm	59.825	1
y,m,p,r,wy,wm	60.117	1

Table 6.A3.5 Optimal lag lengths, United States, 1973:7-1990:6. Money models.

Model	Minimum FPE ($x10^{-6}$)	Optimal lag length
m	33.004	5
m,y	31.271	3
m,y,p	30.411	2
m,y,p,r	25.976	3
m,y,p,r,wm	25.160	1
m,y,p,r,wy	26.008	5
m,y,p,r,wm,wy	26.271	1

c. Granger causality tests.

i. Income models. Tables 6.A3.6 and 6.A3.7 display the money-to-income Granger causality tests results. In the models with only domestic variables (Table 6.A3.6), the null of money to income Granger causality cannot be rejected at the 5 percent significance level. When international variables are added, the F-statistics are generally lower, but money still Granger-causes income at the 5 percent significance level.

Table 6.A3.6 Granger causality tests, United States, 1973:7-1990:6. Income models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m	(4, 191)	4.034	Yes
y/m,p	(4, 187)	3.242	Yes
y/m,p,r	(4, 186)	3.010	Yes

Critical value: 2.42 (5% significance level)
3.41 (1% significance level)

Table 6.A3.7 Granger causality tests, United States, 1973:7-1990:6. Income models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m,p,r,wy	(4, 185)	3.182	Yes
y/m,p,r,wm	(4, 185)	2.944	Yes
y/m,p,r,wy,wm	(4, 184)	3.052	Yes

Critical value: 2.42 (5% significance level)
3.41 (1% significance level)

ii. Money models. Tables 6.A3.8 and 6.A3.9 show the income-money Granger causality results. In the models with only domestic variables, income to money Granger causality cannot be supported. When international variables are added, the F-statistics drop markedly in two of the three models and there is even less evidence that income Granger-causes money.

Table 6.A3.8 Granger causality tests, United States, 1973:7-1990:6. Money models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y	(3, 194)	1.811	No
m/y,p	(3, 192)	1.573	No
m/y,p,r	(3, 189)	1.749	No

Critical value: 2.65 (5% significance level)
2.11 (10% significance level)

Table 6.A3.9 Granger causality tests, United States, 1973:7-1990:6. Money models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y,p,r,wy	(3, 184)	0.252	No
m/y,p,r,wm	(3, 188)	1.558	No
m/y,p,r,wm,wy	(3, 187)	0.202	No

Critical value: 2.65 (5% significance level)
2.11 (10% significance level)

B. Canada

1. Full Sample: 1961:1 - 1990:6:

Table 6.B1.1 shows the results of the tests for unit roots and time trends. Domestic income, domestic interest rates, world income and world money have one unit root and a quadratic time trend each. Domestic money has one unit root and no time trend or drift, while prices have two unit roots and a linear time trend. The cointegration results shown in Tables 6.B1.2 and 6.B1.3 exhibit no evidence of cointegration among any of the series.

Tables 6.B1.4 and 6.B1.5 show the optimal lag lengths defined through the procedure presented in Chapter V. These lag lengths are used to specify the models used for Granger causality testing. The results of the money-income causality tests are displayed in Tables 6.B1.6 and 6.B1.7. When only domestic variables are included, money clearly Granger-causes income. Adding international variables increases the F-statistics, and therefore the null of no Granger causality from money to income can be rejected at an even lower significance level.

Tables 6.B1.8 and 6.B1.9 show the results of the income-money Granger causality results. The hypothesis of no income-money causality is rejected at the 1 percent significance level in all models with domestic variables only. Including international variables only increases the F-statistics.

Table 6.B1.1 Tests for unit roots and time trends, Canada, 1961:1-1990:6.

Series	$\tau[X]$	$\tau[\Delta X]$	Number of Unit Roots	Time	Constant
y	-2.670	-5.080	1	2.123	2.213
m	-0.760	-6.469	1	0.566	1.500
p	-1.672	-3.175	2	-0.017	2.539
r	-2.437	-7.986	1	2.181	1.943
wy	-2.371	-5.441	1	2.123	1.698
wm	-2.242	-5.267	1	2.860	2.394

Critical values: -3.425 (N=342, 5% Significance Level)

Table 6.B1.2 Cointegration tests, Canada, 1961:1-1990:6
Income models.

Model	$\tau[Z]$	Critical value	Cointegrated?
y,m	-2.891	-3.355	No
y,m,p	-2.784	-3.767	No
y,m,p,r	-3.085	-4.131	No
y,m,p,r,wy	-3.433	-4.459	No
y,m,p,r,wm	-3.193	-4.459	No
y,m,p,r,wy,wm	-2.496	-4.755	No

N=342, 5% significance level

Table 6.B1.3 Cointegration tests, Canada, 1961:1-1990:6
Money models.

Model	$\tau[Z]$	Critical value	Cointegrated?
m,y	-2.336	-3.355	No
m,y,p	-2.179	-3.767	No
m,y,p,r	-3.092	-4.132	No
m,y,p,r,wy	-2.593	-4.459	No
m,y,p,r,wm	-2.228	-4.459	No
m,y,p,r,wm,wy	-2.496	-4.755	No

N=342, 5% significance level

Table 6.B1.4 Optimal lag lengths, Canada, 1961:1-1990:6
Income models.

Model	Minimum FPE ($x10^{-6}$)	Optimal lag length
y	130.17	5
y,m	128.25	2
y,m,p	129.39	1
y,m,p,r	128.82	1
y,m,p,r,wy	129.03	2
y,m,p,r,wm	129.37	1
y,m,p,r,wy,wm	129.16	1

Table 6.B1.5 Optimal lag lengths, Canada, 1961:1-1990:6
Money models.

Model	Minimum FPE ($x10^{-6}$)	Optimal lag length
m	143.50	1
m,y	141.05	12
m,y,p	140.67	10
m,y,p,r	122.34	2
m,y,p,r,wm	121.89	2
m,y,p,r,wy	118.88	4
m,y,p,r,wm,wy	118.63	4

Table 6.B1.6 Granger causality tests, Canada, 1961:1-1990:6
Income models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m	(2, 339)	4.182	Yes
y/m,p	(2, 338)	4.083	Yes
y/m,p,r	(2, 337)	4.586	Yes

Critical value: 3.00 (5% significance level)
4.61 (1% significance level)

Table 6.B1.7 Granger causality tests, Canada, 1961:1-1990:6
Income models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m,p,r,wy	(2, 335)	5.116	Yes
y/m,p,r,wm	(2, 336)	4.204	Yes
y/m,p,r,wy,wm	(2, 334)	4.640	Yes

Critical value: 3.00 (5% significance level)
4.61 (1% significance level)

Table 6.B1.8 Granger causality tests, Canada, 1961:1-1990:6
Money models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y	(12, 326)	2.599	Yes
m/y,p	(12, 316)	2.567	Yes
m/y,p,r	(12, 314)	2.910	Yes

Critical value: 1.75 (5% significance level)
2.18 (1% significance level)

Table 6.B1.9 Granger causality tests, Canada, 1961:1-1990:6
Money models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y,p,r,wy	(12, 310)	2.911	Yes
m/y,p,r,wm	(12, 312)	2.843	Yes
m/y,p,r,wm,wy	(12, 308)	2.981	Yes

Critical value: 1.75 (5% significance level)
2.18 (1% significance level)

2. Fixed Exchange Rate Regime: 1962:1 - 1971:7:

The results of the tests for unit roots and time trends for the fixed exchange rate regime are shown in Table 6.B2.1. From this table, we can see that money and income each have two unit roots and a linear time trend, prices have one unit root and a quadratic time trend, interest rates and world income each have one unit root and a linear time trend, and world money has two unit roots with no time trend or drift.

Because money, income and world money have two unit roots each, their growth rates will have only one unit root. Therefore, the growth rates of these variables are used in the cointegration tests. The cointegration test results (Tables 6.B2.2 and 6.B2.3) indicate that no series are cointegrated. This suggests that money, income and world income should be used in second differences, while prices, interest rates and world income should be used in first differences.

Tables 6.B2.4 and 6.B2.5 show the results of the optimal lag length selection procedure. These results define the lag specifications of the models to be used in the Granger causality tests.

The results of the money-income Granger causality results are presented in Tables 6.B2.6 and 6.B2.7. They suggest that money does not cause income at the 5 percent significance level, or even at the 10 percent level. Adding international variables does not change this conclusion.

Tables 6.B2.8 and 6.B2.9 display the income-money Granger causality results. In all models, the null hypothesis of income-money Granger causality cannot be rejected at the 5 percent significance level.

Table 6.B2.1 Tests for unit roots and time trends, Canada, 1962:1-1971:7.

Series	$\tau[X]$	$\tau[\Delta X]$	Number of Unit Roots	Time	Constant
m	-2.925	-2.959	2	1.070	2.915
y	-2.008	-3.250	2	-1.574	2.504
p	-2.043	-4.569	1	2.323	-0.661
r	-2.037	-3.500	1	1.205	1.956
wm	-2.216	-2.662	2	1.328	1.745
wy	-1.013	-4.013	1	0.743	2.621

Critical value: -3.453 (N=102, 5% significance level)
-3.152 (N=102, 10% significance level)

Table 6.B2.2 Cointegration tests, Canada, 1962:1-1971:7
Income models.

Model	τ[Z]	Critical value	Cointegrated?
y,m	-2.779	-3.397	No
y,m,p	-3.170	-3.826	No
y,m,p,r	-3.375	-4.207	No
y,m,p,r,wy	-1.046	-4.554	No
y,m,p,r,wm	-3.488	-4.554	No
y,m,p,r,wy,wm	0.623	-4.874	No

N=102, significance level= 5%

Table 6.B2.3 Cointegration tests, Canada, 1962:1-1971:7
Money models.

Model	τ[Z]	Critical value	Cointegrated?
m,y	-2.892	-3.397	No
m,y,p	-3.032	-3.826	No
m,y,p,r	-4.055	-4.207	No
m,y,p,r,wy	-4.462	-4.554	No
m,y,p,r,wm	-4.051	-4.554	No
m,y,p,r,wm,wy	-4.466	-4.874	No

N=102, significance level = 5%

Table 6.B2.4 Optimal lag lengths, Canada, 1962:1-1971:7
Income models.

Model	Minimum FPE ($x10^{-6}$)	Optimal lag length
y	127.51	5
y,m	129.85	1
y,m,p	128.13	2
y,m,p,r	131.08	1
y,m,p,r,wy	125.83	3
y,m,p,r,wm	133.06	1
y,m,p,r,wy,wm	125.01	2

Table 6.B2.5 Optimal lag lengths, Canada, 1962:1 - 1971:6
Money models.

Model	Minimum FPE ($x10^{-6}$)	Optimal lag length
m	89.93	11
m,y	87.50	12
m,y,p	91.63	1
m,y,p,r	89.00	5
m,y,p,r,wm	89.09	1
m,y,p,r,wy	90.83	1
m,y,p,r,wm,wy	90.56	1

Table 6.B2.6 Granger causality tests, Canada, 1962:1-1971:7
Income models: domestic variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m	(1, 100)	0.569	No
y/m,p	(1, 97)	0.619	No
y/m,p,r	(1, 96)	0.602	No

Critical value: 3.92 (5% significance level)
2.75 (10% significance level)

Table 6.B2.7 Granger causality tests, Canada, 1962:1-1971:7
Income models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m,p,r,wy	(1, 93)	0.697	No
y/m,p,r,wm	(1, 95)	0.613	No
y/m,p,r,wy,wm	(1, 91)	0.896	No

Critical value: 3.92 (5% significance level)
2.75 (10% significance level)

Table 6.B2.8 Granger causality tests, Canada, 1962:1-1971:7
Money models: domestic variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y	(12, 76)	2.334	Yes
m/y,p	(12, 74)	2.352	Yes
m/y,p,r	(12, 69)	2.404	Yes

Critical value: 1.92 (5% significance level)
2.50 (1% significance level)

Table 6.B2.9 Granger causality tests, Canada, 1962:1-1971:7
Money models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y,p,r,wy	(12, 68)	2.282	Yes
m/y,p,r,wm	(12, 68)	2.267	Yes
m/y,p,r,wm,wy	(12, 67)	2.098	Yes

Critical value: 1.92 (5% significance level.
2.50 (1% significance level)

3. Flexible Exchange Rate Regime: 1973:7 - 1990:6:

Table 6.B3.1 shows the results of the tests for unit roots and time trends. Money has one unit root with no time trend or drift. Income and world income are stationary in levels. Prices and interest rates have one unit root and a linear time trend each. World money has one unit root and a quadratic time trend.

Cointegration tests are conducted on the series that are I(1). The results are displayed in Table 6.B3.2. No series are cointegrated. Money, prices, interest rates, and world money will be used in first differences in the optimal lag length selection procedure and in the Granger causality tests, while income and world income are used in levels.

Tables 6.B3.3 and 6.B3.4 display the results of the optimal lag selection procedure. The optimal lag structures determined through this procedure are utilized to specify the models used for the Granger causality tests.

The results of the money-income Granger causality tests are displayed in Tables 6.B3.5 and 6.B3.6. The null hypothesis of money-income Granger causality cannot be rejected at the 5 percent significance level in any of the models. In the models including international variables, the F-statistics are higher and the null of money-income Granger causality cannot be rejected even at the 1 percent significance level.

Tables 6.B3.7 and 6.B3.8 show mixed income-money Granger causality results. In the model with only domestic income and domestic money, money Granger-causes income at the 5 percent significance level. However, when prices are added and when both prices and interest rates are included, money no longer Granger-causes income. Including world income or world income and world money simultaneously improves the F-statistics and money does Granger-cause income in these cases. However, adding only world money to the domestic variables, does not change the conclusion of no Granger causality from income to money, though it improves the F-statistic significantly.

Table 6.B3.1 Tests for unit roots and time trends, Canada, 1973:7-1990:6.

Series	$\tau[X]$	$\tau[\Delta X]$	Number of Unit Roots	Trend	Constant
m	-1.952	-5.686	1	1.732	1.705
y	-3.605	-3.807	0		
p	-0.112	-4.213	1	-1.053	3.055
r	-1.810	-6.296	1	0.662	2.127
wy	-3.719	-4.331	0		
wm	-2.370	-4.357	1	2.212	2.694

Critical value: -3.434 (N=193, 5% significance level)

Table 6.B3.2 Cointegration tests, Canada, 1973:7-1990:6 Money models.

Model	$\tau[Z]$	Critical value	Cointegrated?
m,p	-1.211	-3.369	No
m,p,r	-1.079	-3.787	No
m,p,r,wm	-2.484	-4.157	No

N=192, 5% significance level

Table 6.B3.3 Optimal lag lengths, Canada, 1973:7-1990:6
Income models.

Model	Minimum FPE ($x10^{-6}$)	Optimal lag length
y	130.85	6
y,m	126.29	2
y,m,p	126.79	4
y,m,p,r	126.47	1
y,m,p,r,wy	121.75	5
y,m,p,r,wm	125.08	1
y,m,p,r,wy,wm	123.80	1

Table 6.B3.4 Optimal lag lengths, Canada, 1973:7 - 1990:6
Money models.

Model	Minimum FPE ($x10^{-6}$)	Optimal lag length
m	192.53	9
m,y	187.80	1
m,y,p	187.34	1
m,y,p,r	163.70	9
m,y,p,r,wm	163.16	1
m,y,p,r,wy	160.05	1
m,y,p,r,wm,wy	162.77	1

Table 6.B3.5 Granger causality tests, Canada, 1973:7-1990:6
Income models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m	(2, 190)	4.909	Yes
y/m,p	(2, 185)	4.634	Yes
y/m,p,r	(2, 184)	5.352	Yes

Critical value: 3.04 (5% significance level)
4.71 (1% significance level)

Table 6.B3.6 Granger causality tests, Canada, 1973:7-1990:6
Income models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m,p,r,wy	(2, 179)	7.418	Yes
y/m,p,r,wm	(2, 182)	5.373	Yes
y/m,p,r,wy,wm	(2, 177)	6.696	Yes

Critical value: 3.04 (5% significance level)
4.71 (1% significance level)

Table 6.B3.7 Granger causality tests, Canada, 1973:7-1990:6
Money models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y	(1, 184)	6.519	Yes
m/y,p	(1, 182)	3.308	No
m/y,p,r	(1, 173)	0.006	No

Critical value: 3.89 (5% significance level)
2.73 (10% significance level)

Table 6.B3.8 Granger causality tests, Canada, 1973:7-1990:6
Money models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y,p,r,wy	(1, 172)	4.925	Yes
m/y,p,r,wm	(1, 171)	2.153	No
m/y,p,r,wm,wy	(1, 170)	4.794	Yes

Critical value: 3.89 (5% significance level)
2.73 (10% significance level)

C. Netherlands

1. Full sample: 1961:1 - 1990:6

Table 6.C1.1 presents the results of the tests for unit roots and time trends. Income, money and prices each have one unit root and a linear time trend. The interest rate is stationary in levels. World income and world money each have one unit root and a quadratic time trend.

The cointegration tests results (Tables 6.C1.2 and 6.C1.3) indicate that no series are cointegrated. These results suggest that first differences of all variables, except r, should be used in the optimal lag length selection procedure and the Granger causality tests. Interest rate r will be used in levels.

The results of the optimal lag length selection procedure are displayed in Tables 6.C1.4 and 6.C1.5. The results of this procedure and the unit root, time trend and cointegration tests are utilized to specify the models used for the Granger causality tests. The money-income Granger causality results are presented in Tables 6.C1.6 and 6.C1.7, while the income-money Granger causality results are shown in Tables 6.C1.8 and 6.C1.9. When only domestic variables are used (Table 6.C1.6), the F-statistics are very low, and the null hypothesis that money Granger-causes income can be rejected even at significance levels much higher than 10 percent.

Adding international variables to the domestic variables (Table 6.C1.7) increases the F-statistics markedly, but not sufficiently to accept the null at the 5 or 10 percent significance level.

From Table 6.C1.8 and 6.C1.9, we can see that the null hypothesis of income-money Granger causality cannot be rejected at the 5 percent significance level in any model. The F-statistics from the models incorporating international variables are higher than the ones from models with domestic variables only, but the results are qualitatively the same.

Table 6.C1.1 Tests for unit roots and time trends, Netherlands, 1961:1-1990:6.

Series	$\tau[X]$	$\tau[\Delta X]$	Number of Unit Roots	Trend	Constant
y	-1.288	-8.602	1	-0.076	3.504
m	-1.068	-6.376	1	0.896	2.856
p	1.239	-5.605	1	-1.821	3.181
r	-3.865	-8.140	0		
wy	-2.371	-5.441	1	2.123	1.698
wm	-2.242	-5.267	1	2.860	2.394

Critical value: -3.425 (N=342, 5% significance level)

Table 6.C1.2 Cointegration test results, Netherlands, 1961:1-1990:6, Income models.

Model	$\tau[Z]$	Critical value (5% S.L.)	Cointegrated?
y,m	-1.524	-3.355	No
y,m,p	-1.422	-3.767	No
y,m,p,wm	-3.447	-4.132	No
y,m,p,wy,wm	-3.056	-4.459	No

N=342, 5% significance level

Table 6.C1.3 Cointegration test results, Netherlands, 1961:1-1990:6, Money models.

Model	$\tau[Z]$	Critical value (5% S.L.)	Cointegrated?
m,y	-0.894	-3.355	No
m,y,p	-1.013	-3.767	No
m,y,p,wy	-3.013	-4.132	No
m,y,p,wm	-3.582	-4.132	No
m,y,p,wm,wp	-1.568	-4.459	No

N=342, 5% significance level

Table 6.C1.4 Optimal lag lengths, Netherlands, 1961:1-1990:6. Income models.

Model	Minimum FPE ($x10^{-6}$)	Optimal lag length
y	528.28	5
y,m	530.77	1
y,m,p	528.58	1
y,m,p,r	512.00	12
y,m,p,r,wy	494.15	1
y,m,p,r,wm	508.27	1
y,m,p,r,wm,wy	490.43	1

Table 6.C1.5 Optimal lag lengths, Netherlands, 1961:1-1990:6. Money models.

Model	Minimum FPE ($x10^{-6}$)	Optimal lag length
m	156.66	3
m,y	155.22	7
m,y,p	153.32	1
m,y,p,r	151.17	2
m,y,p,r,wm	151.18	1
m,y,p,r,wy	151.88	1
m,y,p,r,wm,wy	151.16	1

Table 6.C1.6 Granger causality tests, Netherlands: 1961:1-1990:6. Income models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m	(1, 341)	0.389	No
y/m,p	(1, 340)	0.394	No
y/m,p,r	(1, 322)	1.616	No

Critical value: 3.84 (5% significance level)
2.71 (10% significance level)

Table 6.C1.7 Granger causality tests, Netherlands: 1961:1-1990:6. Income models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m,p,r,wy	(1, 320)	1.648	No
y/m,p,r,wm	(1, 320)	2.171	No
y/m,p,r,wy,wm	(1, 319)	2.289	No

Critical value: 3.84 (5% significance level)
2.71 (10% significance level)

Table 6.C1.8 Granger causality tests, Netherlands, 1961:1-1990:6. Money models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y	(7, 335)	2.372	Yes
m/y,p	(7, 334)	2.379	Yes
m/y,p,r	(7, 332)	2.016	Yes

Critical value: 2.01 (5% significance level)
2.64 (1% significance level)

Table 6.C1.9 Granger causality tests, Netherlands, 1961:1-1990:6. Money models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y,p,r,wy	(7, 330)	2.390	Yes
m/y,p,r,wm	(7, 330)	2.380	Yes
m/y,p,r,wm,wy	(7, 329)	2.411	Yes

Critical value: 2.01 (5% significance level)
2.64 (1% significance level)

2. Fixed Exchange Rate Regime: 1961:1 - 1971:4:

The tests for unit roots and time trends (Table 6.C2.1) indicate that money and world money have two unit roots each. The interest rate has two unit roots, but no significant time trend or drift. Income and world income each have one unit root, but no significant time trend or drift, and prices have one unit root and a quadratic time trend. The tests for cointegration among these series suggest that none of them are cointegrated (see Tables 6.C2.2 and 6.C2.3).

Tables 6.C2.4 and 6.C2.5 present the results of the optimal lag length selection procedure. The results obtained are utilized to specify the models used for the Granger causality tests. The outcome of these tests are presented in Tables 6.C2.6 through 6.C2.9. From Tables 6.C2.6 and 6.C2.7 it can be seen that the null hypothesis of Granger causality from money to income can be rejected at the 10 percent significance level and even higher for all models. The F-statistics of the models including international variables are noticeably lower than those from models with domestic variables only. The hypothesis of Granger causality from income to money can also be rejected at high levels of significance for all models (see Tables 6.C2.8 and 6.C2.9). The models incorporating international variables have higher F-statistics, but not high enough to alter the conclusions.

Table 6.C2.1 Tests for unit roots and time trends, Netherlands, 1961:1-1971:4.

Series	$\tau[X]$	$\tau[\Delta X]$	Number of Unit Roots	Time	Constant
m	-0.744	-2.981	2	1.651	2.972
y	-1.805	-5.204	1	1.878	-0.776
p	-2.941	-5.572	1	3.585	-0.444
r	-1.059	-2.534	2	-1.301	0.251
wm	-2.929	-3.351	2	1.052	2.399
wy	-0.843	-3.798	1	0.915	1.363

Critical value: -3.450 (5% significance level, N=112)

Table 6.C2.2 Cointegration tests, Netherlands, 1961:1-1971:4. Income models.

Model	$\tau[Z]$	Critical value	Cointegrated?
y,m	0.329	-3.392	No
y,m,p	-2.540	-3.819	No
y,m,p,r	-2.547	-4.198	No
y,m,p,r,wy	-2.198	-4.542	No
y,m,p,r,wm	-2.553	-4.542	No
y,m,p,r,wy,wm	-2.206	-4.859	No

N=112, 5% significance level

Table 6.C2.3 Cointegration tests, Netherlands, 1961:1 - 1971:4. Money models.

Model	$\tau[Z]$	Critical value	Cointegrated?
m,y	-3.124	-3.392	No
m,y,p	-3.073	-3.819	No
m,y,p,r	-3.342	-4.198	No
m,y,p,r,wy	-3.862	-4.542	No
m,y,p,r,wm	-3.724	-4.542	No
y,m,p,r,wm,wy	-3.743	-4.859	No

N=112, 5% significance level

Table 6.C2.4 Optimal lag lengths, Netherlands, 1961:1 - 1971:4. Income models.

Model	Minimum FPE $(x10^{-6})$	Optimal lag length
y	239.84	11
y,m	238.29	1
y,m,p	240.17	2
y,m,p,r	239.56	9
y,m,p,r,wy	231.67	3
y,m,p,r,wm	243.98	1
y,m,p,r,wy,wm	239.37	1

Table 6.C2.5 Optimal lag lengths, Netherlands, 1961:1-1971:4. Money models.

Model	Minimum FPE $(x10^{-6})$	Optimal lag length
m	67.67	9
m,y	68.89	1
m,y,p	70.22	3
m,y,p,r	70.58	1
m,y,p,r,wm	70.74	4
m,y,p,r,wy	69.22	2
m,y,p,r,wm,wy	69.80	1

Table 6.C2.6 Granger causality tests, Netherlands, 1961:1-1971:4. Income models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m	(1, 99)	0.644	No
y/m,p	(1, 96)	0.550	No
y/m,p,r	(1, 87)	0.112	No

Critical value: 3.92 (5% significance level)
2.75 (10% significance level)

Table 6.C2.7 Granger causality tests, Netherlands, 1961:1-1971:4. Income models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m,p,r,wy	(1, 84)	0.029	No
y/m,p,r,wm	(1, 86)	0.146	No
y/m,p,r,wy,wm	(1, 83)	0.046	No

Critical value: 3.92 (5% significance level)
2.75 (10% significance level)

Table 6.C2.8 Granger causality tests, Netherlands, 1961:1-1971:4. Money models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y	(1, 102)	0.000	No
m/y,p	(1, 98)	0.027	No
m/y,p,r	(1, 97)	0.002	No

Critical value: 3.92 (5% significance level)
2.75 (10% significance level)

Table 6.C2.9 Granger causality tests, Netherlands, 1961:1-1971:4. Money models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y,p,r,wy	(1, 95)	0.313	No
m/y,p,r,wm	(1, 93)	0.010	No
m/y,p,r,wm,wy	(1, 92)	0.256	No

Critical value: 3.92 (5% significance level)
2.75 (10% significance level)

3. Flexible Exchange Rate Regime: 1973:7 - 1990:6:

Tests for unit roots and time trends indicate that money, income, world money and world income each have one unit root and a quadratic time trend (Table 6.C3.1). The interest rate has one unit root with a linear time trend, and prices have two unit roots. The tests for cointegration suggest that no series are cointegrated (Tables 6.C3.2 and 6.C3.3). The results of the optimal lag length selection procedure are displayed in Tables 6.C3.4 and 6.C3.5.

The results obtained thus far are utilized to specify the models used for the Granger causality tests. Tables 6.C3.6 through 6.C3.9 present the Granger causality test results. The null that money Granger-causes income can be rejected at significance level much higher than 10 percent for all models. The addition of international variables to the models with domestic variables raises the F-statistics, but not sufficiently to alter the conclusions (see Tables 6.C3.6 and 6.C3.7). The null that income Granger-causes money, on the other hand, cannot be rejected at even the 1 percent significance level. Adding international variables to the models with domestic variables somewhat lowers the F-statistics, but not sufficiently to alter the conclusions.

Table 6.C3.1 Tests for unit roots and time trends, Netherlands, 1973:7-1990:6.

Series	$\tau[X]$	$\tau[\Delta X]$	Number of Unit Roots	Trend	Constant
m	-3.289	-5.253	1	3.059	2.346
y	-2.673	-6.735	1	2.552	0.907
p	-1.462	-2.742	2	-2.324	1.393
r	-3.055	-6.355	1	0.056	3.021
wy	-3.368	-4.330	1	3.713	0.323
wm	-2.373	-4.371	1	2.220	2.699

Critical value: -3.434 (N=194, 5% significance level)

Table 6.C3.2 Cointegration tests, Netherlands, 1973:7-1990:6. Income models.

Model	$\tau[Z]$	Critical value	Cointegrated?
y,m	-3.031	-3.369	No
y,m,p	-3.032	-3.787	No
y,m,p,r	-2.885	-4.157	No
y,m,p,r,wy	-3.242	-4.490	No
y,m,p,r,wm	-2.812	-4.490	No
y,m,p,r,wy,wm	-3.331	-4.794	No

N=192, 5% significance level

Table 6.C3.3 Cointegration tests, Netherlands, 1973:7-1990:6. Money models.

Model	$\tau[Z]$	Critical value	Cointegrated?
m,y	-3.224	-3.369	No
m,y,p	-3.125	-3.787	No
m,y,p,r	-2.737	-4.157	No
m,y,p,r,wy	-4.440	-4.490	No
m,y,p,r,wm	-3.196	-4.490	No
m,y,p,r,wm,wy	-3.235	-4.794	No

N=192, 5% significance level

Table 6.C3.4 Optimal lag lengths, Netherlands, 1973:7-1990:6. Income models.

Model	Minimum FPE ($x10^{-6}$)	Optimal lag length
y	718.20	4
y,m	733.27	1
y,m,p	743.64	1
y,m,p,r	732.78	1
y,m,p,r,wy	680.62	1
y,m,p,r,wm	738.09	1
y,m,p,r,wy,wm	687.36	1

Table 6.C3.5 Optimal lag lengths, Netherlands, 1973:7-1990:6. Money models.

Model	Minimum FPE ($x10^{-6}$)	Optimal lag length
m	186.43	1
m,y	177.79	7
m,y,p	180.08	1
m,y,p,r	178.56	1
m,y,p,r,wm	179.45	1
m,y,p,r,wy	179.72	1
m,y,p,r,wm,wy	180.34	1

Table 6.C3.6 Granger causality tests, Netherlands, 1973:7-1990:6. Income models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m	(1, 192)	0.045	No
y/m,p	(1, 191)	0.046	No
y/m,p,r	(1, 190)	0.451	No

Critical value: 3.89 (5% significance level).
2.73 (10% significance level)

Table 6.C3.7 Granger causality tests, Netherlands, 1973:7-1990:6. Income models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m,p,r,wy	(1, 189)	0.425	No
y/m,p,r,wm	(1, 189)	0.606	No
y/m,p,r,wy,wm	(1, 188)	0.487	No

Critical value: 3.89 (5% significance level)
2.73 (10% significance level)

Table 6.C3.8 Granger causality tests, Netherlands, 1973:7-1990:6. Money models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y	(7, 186)	3.474	Yes
m/y,p	(7, 185)	3.444	Yes
m/y,p,r	(7, 184)	3.064	Yes

Critical value: 2.06 (5% significance level)
2.73 (1% significance level)

Table 6.C3.9 Granger causality tests, Netherlands, 1973:7-1990:6. Money models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y,p,r,wy	(7, 183)	3.036	Yes
m/y,p,r,wm	(7, 183)	3.043	Yes
m/y,p,r,wm,wy	(7, 182)	3.018	Yes

Critical value: 2.06 (5% significance level)
2.73 (1% significance level)

CHAPTER VII

RESULTS SUMMARY AND CONCLUSIONS

The major purpose of this study is to reexamine the Granger causality between domestic money and domestic income, within an open economy framework, in light of the new developments in time series analysis. In this chapter, the results presented in Chapter VI are summarized and analyzed with respect to:

1. the impact of international variables on the relationship between domestic money and domestic income; and

2. the impact of different exchange rate regimes.

The results from this study are then contrasted with the predictions of the Mundell-Fleming model presented in Chapter IV. The impact of different lag length specifications on the Granger causality results from this study are briefly discussed. Finally, conclusions are offered.

A. United States

Tables 7.A1 and 7.A2 summarize the results of the Granger causality tests for the United States for all three sample periods considered.

Table 7.A1 Summary of Granger causality results, United States: Does money Granger-cause income?

Sample period	Domestic variables only	All variables
Full sample	Yes*	Yes**
Fixed exchange rate regime	No	No
Flexible exchange rate regime	Yes	Yes

*When interest rates are added, income does not cause money at the 5 percent significance level, but does at a slightly higher than 5 percent level.

**When world money is added, income does not cause money at the 5 percent significance level, but does at the 10 percent significance level.

Table 7.A2 Summary of Granger causality results, United States: Does income Granger-cause money?

Sample period	Domestic variables only	All variables
Full sample	Yes*	No**
Fixed exchange rate regime	No	No
Flexible exchange rate regime	No	No

*When interest rates are added, income does not Granger-cause money at the 5 percent or the 10 percent significance levels.

**Much lower F-statistics than with (y, m, p, r).

1. Granger Causality (Closed Economy):

Over the full sample period, when only domestic variables are considered, money Granger-causes income in the bivariate (y, m), trivariate (y, m, p) and four-variable cases (y, m, p, r)[23], thus confirming Stock and Watson's (1989) findings. This also confirms Christiano and Ljungquist's (1987) conclusion of money-income Granger causality in the bivariate (y, m) case.

Income Granger-causes money in the bivariate (m, y) and trivariate (m, y, p) cases. However, when the interest rate variable is added, income no longer Granger-causes money. This is most likely due to the fact that the co-movements of income and money are common reactions to changes in the interest rate. Therefore, failure to include the interest rate in tests of Granger causality between income and money may lead to spurious results.

2. Granger Causality (Open Economy):

A major objective of this study is to investigate the impact of open economy factors on the relationship between domestic money and domestic income. These factors include two

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[23] In the four-variable case, the significance level is slightly higher than 5 percent.

international variables (world income and world money) and the exchange rate regime.

a. Impact of international variables. Taking explicitly into account international influences on the relationship between US income and US money by including international variables in the Granger causality tests does not qualitatively alter the results over the full sample period. Adding world money and/or world income variables to the four-variable models (y, m, p, r) and (m, y, p, r) generally reduces the F-statistics, but does not change the causality results.

b. Exchange rate regime. The exchange rate regime does appear to have a marked impact on the money-income Granger causality results for the US. Over the fixed exchange rate regime, US money Granger-causes US income in all models. However, over the fixed exchange rate regime, US money does not Granger-cause US income in any of the models. On the other hand, the income-money Granger causality results for the US do not change qualitatively in different exchange rate regimes.

To summarize, in the flexible exchange rate regime there is evidence of unidirectional causality from US money to US income, whereas in the fixed exchange rate regime there is no evidence of Granger causality either way between US money and US income.

B. Canada

The Granger causality results for Canada for all sample periods are summarized in Tables 7.B1 and 7.B2.

Table 7.B1 Summary of Granger causality results, Canada: Does money Granger-cause income?

Sample period	Domestic variables only	All variables
Full sample	Yes	Yes
Fixed exchange rate regime	No	No
Flexible exchange rate regime	Yes	Yes

Table B.2 Summary of Granger causality results, Canada: Does income Granger-cause money?

Sample period	Domestic variables only	All variables
Full sample	Yes	Yes
Fixed exchange rate regime	Yes	Yes
Flexible exchange rate regime	No*	Yes**

*In the bivariate model (y, m), income does Grange-cause money.

**When only world money is added to the domestic variables, income does not cause money at the 5 percent or the 10 percent significance level.

1. Granger Causality (Closed Economy):

Over the full sample, Canadian money does Granger-cause Canadian income in the bivariate (y, m), the trivariate (y, m, p) and the four-variable (y, m, p, r) models. Also, there is strong evidence of Granger causality from Canadian income to Canadian money over the full sample for all domestic model specifications: for all domestic models, the null hypothesis of income-money Granger causality cannot be rejected at even the 1 percent significance level. Therefore, over the full sample, there is strong evidence of a feedback relationship between Canadian money and Canadian income.

2. Granger Causality (Open Economy):

a. Impact of international variables. When international variables (world money and/or world income) are added to the domestic models (y, m, p, r) and (m, y, p, r), the Granger causality conclusions are not altered in the full sample and the fixed exchange rate regime. However, the F-statistics increase in all model specifications, especially in the models including world income. In the flexible exchange rate regime, on the other hand, the addition of world income to the (m, y, p, y) model does change the income to money Granger causality results. Therefore, world income is an important element in the relationship between Canadian domestic income and Canadian domestic money supply. Leaving it out of a study of the Granger causality between Canadian money and Canadian income may lead to spurious results.

b. Exchange rate regime: Tables 7.B1 and 7.B2 show that for Canada, the relationship between money and income is sensitive to the exchange rate regime. Canadian money does not Granger-cause Canadian income in the fixed exchange rate regime, but it does in the flexible exchange rate regime. A conclusion of income to money Granger causality is reached for all model specifications over the fixed exchange rate regime. However, over the flexible exchange rate regime, the income-money Granger causality results are mixed. Canadian income Granger-causes Canadian money in the bivariate model (m, y), and the models including world income (m, y, p, r, wy) and (m, y, p, r, wm, wy), but not in the other models.

C. Netherlands

Tables 7.C1 and 7.C2 summarize the Granger causality test results for the Netherlands over all sample periods.

Table 7.C1 Summary of Granger causality results, Netherlands: Does money Granger-cause income?

Sample period	Domestic variables only	All variables
Full sample	No	No
Fixed exchange rate regime	No	No
Flexible exchange rate regime	No	No

Table 7.C2 Summary of Granger causality results, Netherlands: Does income Granger-cause money?

Sample period	Domestic variables only	All variables
Full sample	Yes	Yes
Fixed exchange rate regime	No	No
Flexible exchange rate regime	Yes	Yes

1. Granger Causality (Closed Economy):

From Table 7.C1 we see that there is no evidence of Granger causality from money to income over the full sample period when only domestic variables are considered. However, income appears to Granger-cause money over that period. Therefore, over the full sample period and when only domestic variables are included, there is evidence of unidirectional causality from income to money for the Netherlands.

2. Granger Causality (Open Economy):

a. Impact of international variables. Adding international variables (world income and/or world money) to the income model including all relevant variables (y, m, p, r) significantly increases the F-statistics, but not sufficiently to alter the Granger causality conclusions over the full sample: money still does not Granger-cause income. The same is also true for the money models: the inclusion of international variables raises the F-statistics, but does not change the conclusion of income-money Granger causality.

b. Exchange rate regime. From Tables 7.C1 and 7.C2 it is apparent that for the Netherlands the Granger causality results are sensitive to the exchange rate regime. Though the money-income Granger causality conclusions are the same for both the fixed and the flexible exchange rate regimes (no causality), the income-money Granger causality conclusions over the fixed exchange rate regime are the opposite of those over the flexible exchange rate regime: income does not Granger-cause money in the first case, but it does in the second case.

D. Comparison with the Mundell-Fleming Model

Chapter IV outlined the Mundell-Fleming model with objective of presenting what this theory predicted the relationship between domestic money and domestic income to be in different scenarios. These predictions are summarized in Table 7.D1. According to the Mundell-Fleming model, in a small economy under a fixed exchange rate regime, there will be unidirectional causality from income to money. Under a flexible exchange rate regime, however, the direction of causality will be reversed and will be from money to income. In a large economy there will be a feedback relationship between money and income under a fixed exchange rate regime, and a unidirectional causality from money to income under a flexible exchange rate regime. By taking the Netherlands and Canada as small economies and the United States as a large economy, these theoretical predictions are contrasted to the empirical results from this study.

Table 7.D1 Money-income causality according to the Mundell-Fleming model.

Exchange rate regime	Small economy	Large economy
Fixed exchange rate regime	y ==> m, m =≠> y	y ==> m, m ==> y
Flexible exchange rate regime	m ==> y, y =≠> m	m ==> y, y =≠> m

Looking at Tables 7.A1 and 7.A2 for the United States, Tables 7.B1 and 7.B2 for Canada and Tables 7.C1 and 7.C2 for the Netherlands, we see that:

1. the empirical results for the United States agree in two out of the four cases (money-income causality, and no income-money causality over the flexible exchange regime).

2. the empirical results for Canada agree in three out of the four cases.

3. the empirical results for the Netherlands agree only in one out of the four cases (money-income causality over the fixed exchange rate regime).

E. Impact of Lag Length Selection

In Appendices C, D, and E, the Granger causality results using the ad-hoc lag length specifications of six and twelve lags are presented for the United States, Canada, and the Netherlands, respectively. From these results, it is clear that the Granger causality results are sensitive to the lag length specification. This result confirms earlier findings by Hsiao [1981], Geweke [1984], Kang [1985], Thornton and Batten [1985], Serlitis [1988] and others, and reinforces the point that an optimal lag length selection criterion, such as the one presented in this study, should be used in Granger causality testing.

F. Conclusions

Recent advances in time series analysis have provided the necessary tools to handle many of the methodological problems that have long plagued Granger causality investigations. A number of researchers have already applied some of these recent advances to investigate the causality relationship between domestic money and domestic income. This project extends the scope of these investigations in several ways. Not only does it pay considerable attention to the trend characteristics (both deterministic and stochastic) of the data, but it also uses an optimality criterion that has been shown to be superior to the alternatives in determining the lag length specifications of the models. The major objective of this dissertation, however, has been to extend the recent investigations of money-income causality into an open economy framework. This is done by taking explicit account of two important international variables (world money and world income), by conducting the study over different exchange rate regimes, and by considering three countries (the United States, Canada, and Netherlands) with different economic sizes and different levels of economic openness. The principal findings of this study are:

1. Except in a few instances, the impact of international factors, as proxied by world money and world income, is not sufficient to alter the direction of causality between domestic money and domestic income.

2. The exchange rate regime is a critical element in the causality relationship between domestic income and domestic money.

3. There is no evidence of causality between US money and US income over the fixed exchange rate regime. However, over the flexible exchange rate regime, there is unidirectional causality from US money to US income.

4. There is unidirectional causality from Canadian income to Canadian money over the fixed exchange rate regime. In the flexible exchange rate regime, Canadian money Granger-causes Canadian income, but the income-money Granger causality results are mixed.

5. There is no evidence of causality between Dutch money and income over the fixed exchange rate regime. Over the flexible exchange rate regime, however, there is evidence of unidirectional causality from Dutch income to Dutch money.

6. The empirical results from this study support the theoretical predictions of the Mundell-Fleming model in six out of twelve cases.

7. The Granger causality results are sensitive to the lag specifications used, thus confirming earlier findings by others. This fact reaffirms the importance of an optimality criterion in the selection of the lag specifications of the models.

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APPENDIX A

DATA

Canada:

Income: Industrial Production Index, 1985=100, S.A. Source: OECD Main Economic Indicators.

Money: Money Supply M1, Billion Canadian Dollars, S.A. Source: OECD Main Economic Indicators.

Prices: Producer Price Index, 1985=100, N.S.A. Source: OECD Main Economic Indicators.

Interest Rates: Treasury Bill Rate (3 Month), Percent per annum. Source: Statistics Canada.

Netherlands:

Income: Industrial Production Index, 1985=100, S.A. Source: OECD Main Economic Indicators.

Money: Money Supply M1, Billion Guilders, S.A. Source: OECD Main Economic Indicators.

Prices: Consumer Price Index, 1985=100, N.S.A. Source: OECD Main Economic Indicators.

Interest Rates: Call Money Rate, Percent per annum, Source: OECD Main Economic Indicators.

United States:

Income: Industrial Production Index, 1985=100, S.A. Source: OECD Main Economic Indicators.

Money: Money Supply M1, Billion Dollars, S.A. Source: OECD Main Economic Indicators.

Prices: Wholesale Price Index, 1985=100, N.S.A.

Source: OECD Main Economic Indicators.

Interest Rates: Treasury Bill Rate (3 Month), Percent per annum. Source: OECD Main Economic Indicators.

APPENDIX B

Table B1 FPE for income: autoregressive specification, United States, 1960:1-1990:6

LAG LENGTH	FPE ($x10^{-6}$)	LAG LENGTH	FPE ($x10^{-6}$)	LAG LENGTH	FPE ($x10^{-6}$)
1	63.194	9	63.229	17	64.101
2	62.229	10	63.503	18	64.183
3	62.034	11	63.819	19	64.175
4	62.259	12	63.396	20	63.994
5	62.121	13	63.723	21	64.302
6	62.475	14	63.207	22	64.652
7	62.661	15	63.440	23	65.025
8	63.027	16	63.730	24	65.532

APPENDIX C

UNITED STATES

Granger Causality Tests Results: Full Sample

1. Six Lags:

a. Income models:

Table C1.1 Granger causality tests, United States, 1960:1-1990:6. Income models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m	(6, 345)	2.695	Yes
y/m,p	(6, 339)	1.971	No
y/m,p,r	(6, 333)	1.553	No

Critical value: 2.10 (5% significance level).

Table C1.2 Granger causality tests, United States, 1960:1-1990:6. Income models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m,p,r,wy	(6, 327)	1.636	No
y/m,p,r,wm	(6, 327)	1.060	No
y/m,p,r,wy,wm	(6, 321)	1.170	No

Critical value: 2.10 (5% significance level).

b. Money models:

Table C1.3 Granger causality tests, United States, 1960:1-1990:6. Money models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y	(6, 345)	1.174	No
m/y,p	(6, 339)	1.216	No
m/y,p,r	(6, 336)	1.257	No

Critical value: 2.10 (5% significance level).

Table C1.4 Granger causality tests, United States, 1960:1-1990:6. Money models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y,p,r,wy	(6, 327)	0.539	No
m/y,p,r,wm	(6, 327)	1.192	No
m/y,p,r,wm,wy	(6, 321)	0.524	No

Critical value: 2.10 (5% significance level).

2. Twelve lags:

a. Income models:

Table C2.1 Granger causality tests, United States, 1960:1-1990:6. Income models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m	(12, 327)	1.319	No
y/m,p	(12, 315)	0.795	No
y/m,p,r	(12, 303)	0.699	No

Critical value: 1.75 (5% significance level).

Table C2.2 Granger causality tests, United States, 1960:1-1990:6. Income models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m,p,r,wy	(12, 291)	0.805	No
y/m,p,r,wm	(12, 291)	0.834	No
y/m,p,r,wy,wm	(12, 279)	1.019	No

Critical value: 1.75 (5% significance level).

b. Money models:

Table C2.3 Granger causality tests, United States, 1960:1-1990:6. Money models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y	(12, 327)	1.598	No
m/y,p	(12, 315)	1.527	No
m/y,p,r	(12, 303)	1.531	No

Critical value: 1.75 (5% significance level).

Table C2.4 Granger causality tests, United States, 1960:1-1990:6. Money models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y,p,r,wy	(12, 291)	0.787	No
m/y,p,r,wm	(12, 291)	1.420	No
m/y,p,r,wm,wy	(12, 279)	0.715	No

Critical value: 1.75 (5% significance level).

APPENDIX D

CANADA

Granger Causality Tests Results: Full Sample

1. Six lags:

a. Income models:

Table D1.1 Granger causality tests, Canada, 1961:1-1990:6
Income models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m	(6, 333)	2.137	Yes
y/m,p	(6, 326)	1.868	No
y/m,p,r	(6, 320)	1.740	No

Critical value: 2.10 (5% significance level).

Table D1.2 Granger causality tests, Canada, 1961:1-1990:6
Income models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m,p,r,wy	(6, 314)	1.990	No
y/m,p,r,wm	(6, 314)	1.764	No
y/m,p,r,wy,wm	(6, 308)	2.010	No

Critical value: 2.10 (5% significance level).

b. Money models:

Table D1.3 Granger causality tests, Canada, 1961:1-1990:6
Money models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y	(6, 333)	1.185	No
m/y,p	(6, 326)	0.978	No
m/y,p,r	(6, 320)	0.979	No

Critical value: 2.10 (5% significance level).

Table D1.4 Granger causality tests, Canada, 1961:1-1990:6
Money models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y,p,r,wy	(6, 314)	1.941	No
m/y,p,r,wm	(6, 314)	0.772	No
m/y,p,r,wm,wy	(6, 308)	1.735	No

Critical value: 2.10 (5% significance level).

2. Twelve lags:

a. Income models:

Table D2.1 Granger causality tests, Canada, 1961:1-1990:6
Income models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m	(12, 315)	1.851	Yes
y/m,p	(12, 302)	1.799	Yes
y/m,p,r	(12, 290)	1.213	No

Critical value: 1.75 (5% significance level).

Table D2.2 Granger causality tests, Canada, 1961:1-1990:6
Income models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m,p,r,wy	(12, 278)	1.550	No
y/m,p,r,wm	(12, 278)	1.174	No
y/m,p,r,wy,wm	(12, 266)	1.529	No

Critical value: 1.75 (5% significance level).

b. Money models:

Table D2.3 Granger causality tests, Canada, 1961:1-1990:6
Money models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y	(12, 315)	2.396	Yes
m/y,p	(12, 302)	2.146	Yes
m/y,p,r	(12, 290)	1.933	Yes

Critical value: 1.75 (5% significance level).

Table D2.4 Granger causality tests, Canada, 1961:1-1990:6
Money models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y,p,r,wy	(12, 278)	2.004	Yes
m/y,p,r,wm	(12, 278)	2.184	Yes
m/y,p,r,wm,wy	(12, 266)	2.147	Yes

Critical value: 1.75 (5% significance level).

APPENDIX E

NETHERLANDS

Granger Causality Tests Results: Full Sample

1. Six lags:

a. Income models:

Table E1.1 Granger causality tests, Netherlands, 1961:1-1990:6. Income models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m	(6, 334)	0.680	No
y/m,p	(6, 328)	0.583	No
y/m,p,r	(6, 322)	0.411	No

Critical value: 2.10 (5% significance level).

Table E1.2 Granger causality tests, Netherlands, 1961:1-1990:6. Income models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m,p,r,wy	(6, 315)	0.591	No
y/m,p,r,wm	(6, 315)	0.494	No
y/m,p,r,wy,wm	(6, 309)	0.633	No

Critical value: 2.10 (5% significance level).

b. Money Models:

Table E1.3 Granger causality tests, Netherlands, 1961:1-1990:6. Money models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y	(6, 334)	1.949	No
m/y,p	(6, 328)	1.997	No
m/y,p,r	(6, 322)	1.569	No

Critical value: 2.10 (5% significance level).

Table E1.4 Granger causality tests, Netherlands, 1961:1-1990:6. Money models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y,p,r,wy	(6, 315)	1.373	No
m/y,p,r,wm	(6, 315)	1.881	No
m/y,p,r,wm,wy	(6, 309)	1.519	No

Critical value: 2.10 (5% significance level).

2. Twelve lags:

a. Income models:

Table E2.1 Granger causality tests, Netherlands, 1961:1-1990:6. Income models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m	(12, 316)	0.890	No
y/m,p	(12, 304)	0.873	No
y/m,p,r	(12, 292)	0.758	No

Critical value: 1.75 (5% significance level).

Table E2.2 Granger causality tests, Netherlands, 1961:1-1990:6. Income models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
y/m,p,r,wy	(12, 279)	0.780	No
y/m,p,r,wm	(12, 279)	0.717	No
y/m,p,r,wy,wm	(12, 267)	0.743	No

Critical value: 1.75 (5% significance level).

b. Money models:

Table E2.3 Granger causality tests, Netherlands, 1961:1-1990:6. Money models: domestic variables only.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y	(12, 316)	2.160	Yes
m/y,p	(12, 304)	2.134	Yes
m/y,p,r	(12, 292)	1.799	Yes

Critical value: 1.75 (5% significance level).

Table E2.4 Granger causality tests, Netherlands, 1961:1-1990:6. Money models: all variables.

Dependent variable / Independent variable	Degrees of freedom	F-statistics	Causality?
m/y,p,r,wy	(12, 279)	1.438	No
m/y,p,r,wm	(12, 279)	1.919	Yes
m/y,p,r,wm,wy	(12, 267)	1.436	No

Critical value: 1.75 (5% significance level).

APPENDIX F

Sample Program: Unit Root Tests

```
*  PROGRAM TO TEST FOR UNIT ROOTS USING THE STOCK-WATSON
*  PROCEDURE IN RATS 3.10
*  COUNTRY: UNITED STATES
*  SAMPLE PERIOD: 1960:1 - 1990:6
*  VARIABLES: Industrial Production Index (IPI), Money Supply
*  (M1), Wholesale Price Index (WPI), 3-month Treasury Bill
*  Rate (TB), World Industrial Production Index (WIPI),
*  and World Money Supply (WM1).


BMA COMPILE 2000
CALENDAR 60 1 12
ALLOCATE 0 90:6
OPEN DATA A:USDAT.RAT
DATA(FORMAT=RATS) / USIPI USM1 USWPI USTB WIPI WM1


* TAKE LOGs OF ALL VARIABLES, EXCEPT T-BILL RATE

SET TREND 1960:1 1990:6 = T
SET LM1 = LOG(USM1(T))
SET LIPI = LOG(USIPI(T))
SET LWPI = LOG(USWPI(T))
SET LWIPI = LOG(WIPI(T))
SET LWM1 = LOG(WM1(T))
SET TB = USTB(T)


* RUN THE UNIT ROOT TESTS USING THE STOCK-WATSON PROCEDURE

SOURCE C:\RATS\STOCKWAT.SRC
@STOCKWAT(ARCORR=6) LM1 1961:1 1990:6
@STOCKWAT(ARCORR=6) LIPI 1961:1 1990:6
@STOCKWAT(ARCORR=6) LWPI 1961:1 1990:6
@STOCKWAT(ARCORR=6) TB 1961:1 1990:6
@STOCKWAT(ARCORR=6) LWM1 1961:1 1990:6
@STOCKWAT(ARCORR=6) LWIPI 1961:1 1990:6
```

APPENDIX G

Sample Program: Cointegration Tests

```
*  PROGRAM TO RUN THE COINTEGRATION TESTS USING THE STOCK-
*  WATSON PROCEDURE IN RATS 3.10
*  COUNTRY: UNITED STATES
*  SAMPLE PERIOD: 1960:1 - 1990:6
*  VARIABLES: Industrial Production Index (IPI), Money Supply
*  (M1), Wholesale Price Index (WPI), 3-month Treasury Bill
*  Rate (TB), World Industrial Production Index (WIPI),
*  and World Money Supply (WM1).


BMA COMPILE 2000
CALENDAR 60 1 12
ALLOCATE 0 90:6
OPEN DATA A:USDAT.RAT
DATA(FORMAT=RATS) / USIPI USM1 USWPI USTB WIPI WM1


* TAKE LOGs OF ALL VARIABLES, EXCEPT T-BILL RATE

SET TREND 1960:1 1990:6 = T
SET LM1 = LOG(USM1(T))
SET LIPI = LOG(USIPI(T))
SET LWPI = LOG(USWPI(T))
SET LWIPI = LOG(WIPI(T))
SET LWM1 = LOG(WM1(T))
SET TB = USTB(T)


* RUN THE COINTEGRATION REGRESSIONS

* 1. INCOME MODELS:

LINREG LIPI 1960:1 1990:6  RYM
# CONSTANT LM1

LINREG LIPI / RYMW
# CONSTANT LM1 LWPI

LINREG LIPI / RYMWR
# CONSTANT LM1 LWPI TB

LINREG LIPI / RYMWR1
```

```
# CONSTANT LM1 LWPI TB LWIPI

LINREG LIPI / RYMWR12
# CONSTANT LM1 LWPI TB LWIPI LWM1


* RUN THE COINTEGRATION TESTS USING THE STOCK-WATSON PROCEDURE

SOURCE C:\RATS\STOCKWAT.SRC
@STOCKWAT(ARCORR=6) RYM 1961:1 1990:6
@STOCKWAT(ARCORR=6) RYMW 1961:1 1990:6
@STOCKWAT(ARCORR=6) RYMWR 1961:1 1990:6
@STOCKWAT(ARCORR=6) RYMWR1 1961:1 1990:6
@STOCKWAT(ARCORR=6) RYMWR12 1961:1 1990:6



* 2. MONEY SUPPLY MODELS:


LINREG LM1 1960:1 1990:6  RMY
# CONSTANT LIPI

LINREG LM1 / RMYW
# CONSTANT LIPI LWPI

LINREG LM1 / RMYWR
# CONSTANT LIPI LWPI TB

LINREG LM1 / RMYWR1
# CONSTANT LIPI LWPI TB LWM1

LINREG LM1 / RMYWR12
# CONSTANT LIPI LWPI TB LWM1 LWIPI


* RUN THE COINTEGRATION TESTS USING THE STOCK-WATSON PROCEDURE


SOURCE C:\RATS\STOCKWAT.SRC
@STOCKWAT(ARCORR=6) RMY 1961:1 1990:6
@STOCKWAT(ARCORR=6) RMYW 1961:1 1990:6
@STOCKWAT(ARCORR=6) RMYWR 1961:1 1990:6
@STOCKWAT(ARCORR=6) RMYWR1 1961:1 1990:6
@STOCKWAT(ARCORR=6) RMYWR12 1961:1 1990:6
```

APPENDIX H

Sample Programs: Lag Length Selection Tests

```
*   LAG LENGTH SELECTION: PROGRAM #1
*   COUNTRY: UNITED STATES
*   SAMPLE PERIOD: 1960:1 - 1990:6
*   INCOME MODELS
*   VARIABLE: Industrial Production Index (IPI)


CALENDAR 60 1 12
ALLOCATE 0 90:6
OPEN DATA A:USDAT.RAT
DATA(FORMAT=RATS) / USIPI


* TAKE LOG OF THE VARIABLE

SET TREND 1960:1 1990:6 = T
SET LIPI = LOG(USIPI(T))


* TAKE THE DIFFERENCE OF THE VARIABLE

DIFF LIPI / D1LIPI


* RUN THE FPE TEST

CMOM
# CONSTANT TREND D1LIPI{1 TO 24} D1LIPI
DISPLAY '     LAGS            FPE'
DO MAXLAG=1,24
   LINREG(CMOM,NOPRINT) D1LIPI
   # CONSTANT TREND D1LIPI{1 TO MAXLAG}
   EVAL FPE = ((RSS/NOBS)*(NOBS+NREG)/(NOBS-NREG))*1000000
   DISPLAY @1 ##### MAXLAG  @12 ###.##### FPE
END DO
END
```

```
*  LAG LENGTH SELECTION: PROGRAM #2
*  COUNTRY: UNITED STATES
*  SAMPLE PERIOD: 1960:1 - 1990:6
* INCOME MODELS VARIABLES: Industrial Production Index (IPI),
*  Money Supply (M1)


CALENDAR 60 1 12
ALLOCATE 0 90:6
OPEN DATA A:USDAT.RAT
DATA(FORMAT=RATS) / USIPI USM1

* TAKE LOGs OF THE VARIABLES

SET TREND 1960:1 1990:6 = T
SET LM1 = LOG(USM1(T))
SET LIPI = LOG(USIPI(T))


* TAKE DIFFERENCES OF THE VARIABLES

DIFF LIPI / D1LIPI
DIFF LM1 / D1LM1


* RUN THE FPE TEST

CMOM
# CONSTANT TREND D1LIPI{1 TO 3} D1LM1{1 TO 24} D1LIPI
DISPLAY '     LAGS             FPE'
DO MAXLAG=1,24
   LINREG(CMOM,NOPRINT) D1LIPI
   # CONSTANT TREND D1LIPI{1 TO 3} D1LM1{1 TO MAXLAG}
   EVAL FPE = ((RSS/NOBS)*(NOBS+NREG)/(NOBS-NREG))*1000000
   DISPLAY @1 ##### MAXLAG  @12 ###.##### FPE
END DO
END
```

```
*  LAG LENGTH SELECTION: PROGRAM #3
*  COUNTRY: UNITED STATES
*  SAMPLE PERIOD: 1960:1 - 1990:6
*  INCOME MODELS
*  VARIABLES: Industrial Production Index (IPI), Money Supply
*  (M1), Wholesale Price Index (WPI)


CALENDAR 60 1 12
ALLOCATE 0 90:6
OPEN DATA A:USDAT.RAT
DATA(FORMAT=RATS) / USIPI USM1 USWPI

* TAKE LOGs OF THE VARIABLES

SET TREND 1960:1 1990:6 = T
SET LM1 = LOG(USM1(T))
SET LIPI = LOG(USIPI(T))
SET LWPI = LOG(USWPI(T))


* TAKE DIFFERENCES OF THE VARIABLES

DIFF LIPI / D1LIPI
DIFF LM1 / D1LM1
DIFF LWPI / D1LWPI

* RUN THE FPE TEST

CMOM
# CONSTANT TREND D1LIPI{1 TO 3} D1LM1{1 TO 4} $
     D1LWPI{1 TO 24} D1LIPI
DISPLAY '     LAGS              FPE'
DO MAXLAG=1,24
   LINREG(CMOM,NOPRINT) D1LIPI
   # CONSTANT TREND D1LIPI{1 TO 3} D1LM1{1 TO 4} $
     D1LWPI{1 TO MAXLAG}
   EVAL FPE = ((RSS/NOBS)*(NOBS+NREG)/(NOBS-NREG))*1000000
   DISPLAY @1 ##### MAXLAG  @12 ###.##### FPE
END DO
END
```

```
*  LAG LENGTH SELECTION: PROGRAM #4
*  COUNTRY: UNITED STATES
*  SAMPLE PERIOD: 1960:1 - 1990:6
*  INCOME MODELS
*  VARIABLES: Industrial Production Index (IPI), Money Supply
*  (M1), Wholesale Price Index (WPI), 3-month Treasury Bill
*  Rate (TB).


CALENDAR 60 1 12
ALLOCATE 0 90:6
OPEN DATA A:USDAT.RAT
DATA(FORMAT=RATS) / USIPI USM1 USWPI USTB

* TAKE LOGs OF THE VARIABLES

SET TREND 1960:1 1990:6 = T
SET LM1 = LOG(USM1(T))
SET LIPI = LOG(USIPI(T))
SET LWPI = LOG(USWPI(T))

SET TB = USTB(T)


* TAKE DIFFERENCES OF THE VARIABLES

DIFF LIPI / D1LIPI
DIFF LM1 / D1LM1
DIFF LWPI / D1LWPI
DIFF TB / D1TB


* RUN THE FPE TEST

CMOM
# CONSTANT TREND D1LIPI{1 TO 3} D1LM1{1 TO 4} $
     D1LWPI{1 TO 5} D1TB{1 TO 24}  D1LIPI
DISPLAY '      LAGS              FPE'
DO MAXLAG=1,24
   LINREG(CMOM,NOPRINT) D1LIPI
   # CONSTANT TREND D1LIPI{1 TO 3} D1LM1{1 TO 4} $
     D1LWPI{1 TO 5} D1TB{1 TO MAXLAG}
   EVAL FPE = ((RSS/NOBS)*(NOBS+NREG)/(NOBS-NREG))*1000000
   DISPLAY @1 ##### MAXLAG  @12 ###.##### FPE
END DO
END
```

```
*  LAG LENGTH SELECTION: PROGRAM #5
*  COUNTRY: UNITED STATES
*  SAMPLE PERIOD: 1960:1 - 1990:6
*  INCOME MODELS
*  VARIABLES: Industrial Production Index (IPI), Money Supply
*  (M1), Wholesale Price Index (WPI), 3-month Treasury Bill
*  Rate (TB), World Industrial Production Index (WIPI)


CALENDAR 60 1 12
ALLOCATE 0 90:6
OPEN DATA A:USDAT.RAT
DATA(FORMAT=RATS) / USIPI USM1 USWPI USTB WIPI

* TAKE LOGs OF THE VARIABLES

SET TREND 1960:1 1990:6 = T
SET LM1 = LOG(USM1(T))
SET LIPI = LOG(USIPI(T))
SET LWPI = LOG(USWPI(T))
SET LWIPI = LOG(WIPI(T))

SET TB = USTB(T)


* TAKE DIFFERENCES OF THE VARIABLES

DIFF LIPI / D1LIPI
DIFF LM1 / D1LM1
DIFF LWPI / D1LWPI
DIFF TB / D1TB
DIFF LWIPI / D1LWIPI

* RUN THE FPE TEST

CMOM
# CONSTANT TREND D1LIPI{1 TO 3} D1LM1{1 TO 4} $
  D1LWPI{1 TO 5} D1TB{1} D1LWIPI{1 TO 24} D1LIPI
DISPLAY '     LAGS              FPE'
DO MAXLAG=1,24
   LINREG(CMOM,NOPRINT) D1LIPI
   # CONSTANT TREND D1LIPI{1 TO 3} D1LM1{1 TO 4} $
     D1LWPI{1 TO 5) D1TB{1} D1LWIPI{1 TO MAXLAG}
   EVAL FPE = ((RSS/NOBS)*(NOBS+NREG)/(NOBS-NREG))*1000000
   DISPLAY @1 ##### MAXLAG  @12 ###.##### FPE
END DO
END
```

```
*  LAG LENGTH SELECTION: PROGRAM #6
*  COUNTRY: UNITED STATES
*  SAMPLE PERIOD: 1960:1 - 1990:6
*  INCOME MODELS
*  VARIABLES: Industrial Production Index (IPI), Money Supply
*  (M1), Wholesale Price Index (WPI), 3-month Treasury Bill
*  Rate (TB), World Industrial Production Index (WIPI), World
*  Money Supply (WM1)


CALENDAR 60 1 12
ALLOCATE 0 90:6
OPEN DATA A:USDAT.RAT
DATA(FORMAT=RATS) / USIPI USM1 USWPI USTB WIPI WM1

* TAKE LOGs OF THE VARIABLES

SET TREND 1960:1 1990:6 = T
SET LM1 = LOG(USM1(T))
SET LIPI = LOG(USIPI(T))
SET LWPI = LOG(USWPI(T))
SET LWIPI = LOG(WIPI(T))
SET LWM1 = LOG(WM1(T))

SET TB = USTB(T)

* TAKE DIFFERENCES OF THE VARIABLES

DIFF LIPI / D1LIPI
DIFF LM1 / D1LM1
DIFF LWPI / D1LWPI
DIFF TB / D1TB
DIFF LWIPI / D1LWIPI
DIFF LWM1 / D1WLM1


* RUN THE FPE TEST

CMOM
# CONSTANT TREND D1LIPI{1 TO 3} D1LM1{1 TO 4} $
  D1LWPI{1 TO 5} D1TB{1} D1LWIPI{1 TO 2}      $
  D1LWM1{1 TO 24} D1LIPI
DISPLAY '     LAGS              FPE'
DO MAXLAG=1,24
   LINREG(CMOM,NOPRINT) D1LIPI
   # CONSTANT TREND D1LIPI{1 TO 3} D1LM1{1 TO 4}    $
     D1LWPI{1 TO 5) D1TB{1} D1LWIPI{1 TO 2}         $
     D1LWM1{1 TO MAXLAG}
   EVAL FPE = ((RSS/NOBS)*(NOBS+NREG)/(NOBS-NREG))*1000000
   DISPLAY @1 ##### MAXLAG  @12 ###.##### FPE
END DO
END
```

APPENDIX I

Sample Programs: Granger Causality Tests

```
*  GRANGER CAUSALITY TESTS
*  COUNTRY: UNITED STATES
*  SAMPLE PERIOD: 1960:1 - 1990:6
*  INCOME MODELS
*  VARIABLES: Industrial Production Index (IPI), Money Supply
*  (M1), Wholesale Price Index (WPI), 3-month Treasury Bill
*  Rate (TB), World Industrial Production Index (WIPI), World
*  Money Supply (WM1)


CALENDAR 60 1 12
ALLOCATE 0 90:6
OPEN DATA A:USDAT.RAT
DATA(FORMAT=RATS) / USIPI USM1 USWPI USTB WIPI WM1


* TAKE LOGs OF THE VARIABLES

SET TREND 1960:1 1990:6 = T
SET LM1 = LOG(USM1(T))
SET LIPI = LOG(USIPI(T))
SET LWPI = LOG(USWPI(T))
SET LWIPI = LOG(WIPI(T))
SET LWM1 = LOG(WM1(T))

SET TB = USTB(T)


* TAKE DIFFERENCES OF THE VARIABLES

DIFF LIPI / D1LIPI
DIFF LM1 / D1LM1
DIFF LWPI / D1LWPI
DIFF TB / D1TB
DIFF LWIPI / D1LWIPI
DIFF LWM1 / D1LWM1


* RUN THE GRANGER CAUSALITY TESTS

* MODEL 1: Y, M
```

```
LINREG D1LIPI
# CONSTANT TREND D1LIPI{1 TO 3} D1LM1{1 TO 4}

EXCLUDE
# D1LM1{1 TO 4}


* MODEL 2: Y, M, P

LINREG D1LIPI
# CONSTANT TREND D1LIPI{1 TO 3} D1LM1{1 TO 4} D1LWPI{1 TO 5}

EXCLUDE
# D1LM1{1 TO 4}


* MODEL 3: Y, M, P, R

LINREG D1LIPI
# CONSTANT TREND D1LIPI{1 TO 3} D1LM1{1 TO 4} $
   D1LWPI{1 TO 5} D1TB{1}

EXCLUDE
# D1LM1{1 TO 4}


* MODEL 4: Y, M, P, R, WY

LINREG D1LIPI
# CONSTANT TREND D1LIPI{1 TO 3} D1LM1{1 TO 4} $
   D1LWPI{1 TO 5} D1TB{1} D1LWIPI{1 TO 2}

EXCLUDE
# D1LM1{1 TO 4}


* MODEL 5: Y, M, P, R, WY, WM

LINREG D1LIPI
# CONSTANT TREND D1LIPI{1 TO 3} D1LM1{1 TO 4} $
   D1LWPI{1 TO 5} D1TB{1} D1LWIPI{1 TO 2} D1LWM1{1 TO 2}

EXCLUDE
# D1LM1{1 TO 4}
```