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# **Assessing the Causal Relationship between Euro-Area Money and Price in a Time- Varying Environment**

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## ABSTRACT

The paper provides new evidence on the causal relationship between money and price for the euro area using quarterly data for the period 1980 to 2006, employing two alternative methods of estimation: the vector error correction (VEC) and time-varying coefficient (TVC) estimation techniques. The latter technique has the advantage over the former technique in that it can deal with possible specification biases and spurious relationships that may have arisen from structural changes. The empirical results from the VEC method reveal a bidirectional causal relationship between money and price. Contrary, the results from the TVC technique suggest that money is acting as an exogenous process determining the price level.

*Keywords:* Causality; VEC, time varying coefficient estimation; Euro area

*JEL classification:* C20; E41

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## 1. Introduction

One of the oldest themes in macroeconomics has been the relationship between money and prices. Although **economic theory suggests the mechanisms through which money and prices could influence each other**, the issue of **money being affected by prices and vice-versa** has been a subject of considerable debate.<sup>1</sup> Over **the years econometricians and statisticians have** developed a number of approaches which allow us to more fully explore the causality which lies behind the **connection between money and prices**.<sup>2</sup> **There are many practical obstacles to success in resolving** this issue of causality. In this paper we make use of two **sets of techniques to answer these questions. These two sets of techniques are:** A co-integrating **Vector Autoregression (VEC) approach** and a **Time-Varying Coefficient (TVC) approach**.

The VEC approach allows us to build a detailed **linear** structural model including what we believe are the main long-run drivers for money and prices.<sup>3</sup> This approach rests on the assumption **of linear** structure to our model. Because of the possibility that our model may **be seriously misspecified** we also **use** the TVC approach which is designed to overcome a wide range of model **misspecifications**. Our strategy therefore is to exploit the theoretical structures that we believe are correct as fully as possible. We are also guarding ourselves against a possibility that our results are due to model **misspecifications**.

In **particular**, we apply these approaches to euro area data. A number of previous researchers have investigated the issue of causality between money and prices **using euro area data**.

The **remainder** of this paper is structured as follows. Section 2 presents the theoretical framework and describes the two theoretical approaches used. Section 3 presents the data and the empirical results. Section 4 **concludes**.

## 2. Theoretical and Empirical Underpinnings

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<sup>1</sup> For example, according to the classical dichotomy the relative prices are determined by the supply of and the demand for real goods and services in the real sector and the price level is undetermined.

<sup>2</sup> **Discussions** about causality testing are provided by Granger ( ) Pratt and Schlaifer (1984, 1988), Basmann (1988), Zellner (1979, 1988), Swamy and Tavlas (2007) and Swamy, Tavlas and Mehta (2007).

<sup>3</sup> For example, it is shown by Friedman ( ) that the long-run Phillips curve is vertical. (George, can you find the reference to Friedman?)

## 2.1 Theoretical Framework

Our aim is to investigate the direction of causality between money and prices. To this end, we need to consider theoretical relationships that might underlie and **characterize** the causal relationships involved. The first relationship that we consider is **given by** the portfolio-balance framework, which is often used to determine the demand for money.<sup>4</sup> The underlying theory implies **a behavioral relationship** between money, real income, wealth, prices, and **interest rates** of the following form:

$$f(m, y, w, r^m - \dot{p}^e, r^e - \dot{p}^e, p, \mathbf{u}) = 0 \quad (1)$$

where **m** is the log of nominal M3, **y** is the log of real income, **w** is the log of the real value of wealth, **r<sup>m</sup>** is the own rate of return on money,  **$\dot{p}^e$**  is the expected inflation rate, **r<sup>e</sup>** is the rate of return on **equities**, **p** is the log of the price level and **u** is the **vector of all other variables that are unknown but may belong in equation (1)**. In (1), real rates of return are approximated by nominal rates minus the expected inflation rate.

We **assume** rate-of-return homogeneity of degree zero, implying that, if all rates of return change by x per cent, real quantities of assets in investors' portfolios relative to real income and real wealth will not change. Thus, only the rate-of-return differential, i.e., **r<sup>e</sup>-r<sup>m</sup>**, affects the **behavioral** relationship. We also use **the ratio of wealth to income**, instead of just wealth. The functional form of model (1) may (as usually assumed) or may not be linear. Part of our analysis, **using the VEC approach**, will assume linearity and part of our analysis, using the TVC approach, will not impose the linearity assumption.

Three other long-run structural relationships, in addition to the portfolio balance **relationship that** might underlie the set of variables in equation (1) include: (i) a determination of real income, (ii) a determination of **the ratio of** wealth to income, (iii) a determination of **prices**. These relationships are functions of the **variables in (1)**, and we will discuss formal identification **of these relationships below**.

Thus, **equation (1)** suggests a dynamic **system that includes** at least four underlying structural relationships. Under this set-up, we can think about causality, in **several ways**. (1) We can think about an absolute notion of causality which will imply that any of these four relationships **drives** a particular variable. This would be

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<sup>4</sup> See Brainard-Tobin (1968).

equivalent to weak exogeneity or long-run causality in a standard linear dynamic model. (2) Once we have defined the structural relationships by a set of formal identification conditions we can go beyond the idea of absolute causality to ask if we might associate the causality with a particular structural relationship. If this is possible we may be able to interpret the source of the causality in a structural manner. That is, instead of simply saying that money **affects prices** or money is affected by prices in a general way, we may be able to identify the particular channel through which **monetary policy controls inflation** or money is affected by prices (i.e., through the portfolio balance relationship). This will give us more powerful hypothesis tests as we will be testing individual parameters rather than groups of parameters. **The validity of this depends on appropriate corrections for our misspecifications of the so-called structural relationships. We indicate below how such corrections might be made.**

## 2.2 *Estimation Approaches*

In this paper, two estimation procedures - - VEC and TVC - - are used to assess the causal relationship between money and prices. These approaches are very different in nature, but have a surprisingly common underlying philosophy.

The VEC procedure is an implementation of the approach to modeling developed within the dynamic modeling tradition (for a detailed account, see Cuthbertson, Hall and Taylor (1991)). This approach begins from a general statement of the true economic system, referred to as the data generation process (DGP). The DGP, by definition, is correct and well-specified, but the approach also recognizes that no empirical model can fully capture the DGP. The process of modeling is viewed as an attempt to provide a reasonable approximation to the DGP (a congruent model) through an iterative search procedure involving marginalizing, conditioning and model specification, and an extensive formal set of econometric tests. Even at the end of a successful modeling exercise, a claim of having uncovered the truth cannot be made. All that can be claimed is that a reasonable approximation to certain aspects of the DGP has been found.

The TVC approach (for descriptions, see Swamy and Tavlas (1995, 2001, 2005, 2007)) also takes as its point of departure the idea that there is a true, **changing** economy. Unlike the VEC approach, however, the TVC approach takes the view that

any econometric model is almost certainly a misspecified version of the truth. This misspecification may take the form of omitted variables, endogeneity problems, measurement errors, and incorrect functional form (broadly, the dynamic modeling ideas of marginalization, conditioning and model specification). These problems are expected to **lead to** coefficients that will be unstable and time-varying. Hence, a TVC estimation technique is used that tries to identify the causes of the coefficient instability by using a set of ‘driving’ variables.<sup>5</sup> The idea underlying the technique is to, first, estimate a model with coefficients that are allowed to vary as a result of the fundamental misspecifications in the model, and, then, to identify the specification biases that are occurring in the underlying coefficients and to remove them. If the process is successfully done, we observe a set of biased coefficients, which should exhibit considerable time variation, and a set of bias-corrected coefficients; the latter should reveal the underlying stable parameters of interest.<sup>6</sup>

A great advantage of the TVC approach is that it is robust to the true model being highly non-linear. Non-linearity, of course, is almost certainly the case and we can often see serious problems with standard linear models. For example, a consumption function might find an income elasticity to be above 1. This result, however, cannot be a permanent feature of a model because, if income grows continuously, consumption would eventually become larger than total income. In fact, either the model must be non-linear or the coefficients must change to ensure that this impossible event does not occur. The TVC approach does exactly this. The VEC approach, therefore, can only really be seen as a local approximation to the true non-linear model. Typically, we would expect that the condition is difficult to specify. In the context of our study, an issue is whether the approximation is a useful and congruent one.

In practice, the VEC approach usually begins by testing for the existence of a long-run equilibrium, or co-integrating, relationship among the variables in equation (1). If such a relationship exists, it is augmented with lagged differences of those variables and other stationary variables that economic theory may suggest as belonging in equation (1) in an attempt to capture the short-run dynamics of the variables in the system. Standard methodology employs a three-step procedure. In the

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<sup>5</sup> As noted below, these variables are called “coefficient drivers”.

<sup>6</sup> In contrast to the VEC approach, the TVC approach involves no pretesting. For criticisms of pretesting, see Maddala and Kim (1998, pp. 229-231) and Friedman and Schwartz (1991, pp. 47-49).

first step, the variables are tested for stationarity. The second step involves vector autoregressive (VAR) estimation and misspecification testing, and tests for co-integration. Provided that one or more co-integrating relationships exist, the third step involves the estimation of a VEC specification containing the co-integrating relationship(s), lagged first differences of the variables in the co-integrating relationship(s), and any stationary variables thought to influence the relationship considered.

Under the TVC approach, the coefficient of each explanatory variable can be viewed as the sum of three terms: (1) a component measuring the effect of the explanatory variable on the dependent variable without specification bias, that is, the bias-free component, (2) the omitted-variables bias component, and (3) the measurement-error-bias component.<sup>7</sup> We are interested in **knowing the value of** the bias-free component because if it is zero the relationship between a dependent variable and the explanatory variable is considered to be spurious.<sup>8</sup> To separate this component from the remaining two components, we use “coefficient drivers” in conjunction with the TVC model.<sup>9</sup> Intuitively, coefficient drivers, which should be distinguished from instrumental variables, may be thought of as variables, though not part of the structural equation being estimated, that serve two purposes. First, they deal with the correlation between the included explanatory variables and **their coefficients**.<sup>10</sup> In other words, even though it can be shown that the included explanatory variables are not unconditionally independent of their coefficients, they can be conditionally independent of their coefficients given the coefficient drivers. Second, the coefficient drivers allow us to decompose the coefficients of the TVC model into their respective components.

### 3. Data and Empirical Results

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<sup>7</sup> The intercept of (1) also consists of three components (Swamy and Tavlas, 2001).

<sup>8</sup> See Swamy, Tavlas and Mehta (2007). The definition of spurious regression presented by **these** authors, **unlike Granger and Newbold’s (1974) definition**, applies to both linear and non-linear regression models and takes into account the specification biases contained in the coefficients of **these** models.

<sup>9</sup> The TVC procedure is required because each of the three components is likely to be time-varying. All the three components are time-varying if the underlying “true” model is non-linear. The omitted-variables bias component is time-varying if the set of omitted variables changes over time and the relationship between included and excluded variables is non-linear. The measurement-error-bias component is time-varying if these errors change over time.

<sup>10</sup> A formal definition of coefficient drivers is provided in Swamy and Tavlas (2006).

The estimates reported below are based on quarterly data for the euro area over the period 1980:Q1 – 2006:Q3. The variables used are broad money (M3), real GDP, nominal GDP, the GDP deflator, the own rate on M3, oil prices (in euros), and a measure of euro-area stock prices.<sup>11</sup> As discussed below, the latter variable (euro-area stock prices) was used to construct a proxy for euro-area wealth and to derive a measure of the rate of return on equities.<sup>12</sup> The measure of euro-area nominal stock prices was approximated using the German stock-market-price index<sup>13</sup> for the period 1980:Q1 to 1986:Q4 (because a euro-area European stock price index was not available for this period) and the Dow Jones Euro Stock index from 1987:Q1 to 2006:Q3.<sup>14</sup>

The nominal stock of M3 was measured by the log of M3, denoted by  $m$ . Real income,  $y$ , was measured as the log of real GDP. A problem that we faced is that a comprehensive wealth variable for the euro-area does not exist. Hence, a proxy for the log of real wealth to real income ratio ( $w-y$ ) was constructed as the log of the ratio of observed stock prices to nominal income (log of real stock prices minus log of real income). That is, we used the stock market variable as a proxy for wealth; the proxy was employed to construct a variable that captures the difference between real wealth (as reflected by real stock-market valuation) and real income. The variable representing the spread on return on equities ( $r^e - r^m$ ) is the quarterly percent change in our stock-market valuation variable minus the own rate of return on M3. Finally, the variable for the price level  $p$  is the log of GDP deflator.

Assuming that all these variable follow linear relationships, their time series properties were evaluated employing standard unit-root tests - - the augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and Kwiatkowski et al. (KPSS) tests.<sup>15</sup> All these tests suggested that nominal money, real income, the ratio of real wealth to real income and price level were (unit-root) non-stationary, while their first differences were stationary. The spread between stock returns (annual percentage change in stock prices) and the own rate on M3 was  $I(0)$ . Consequently, nominal

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<sup>11</sup> Oil prices were originally in dollars but were converted into euros using market exchange rates.

<sup>12</sup> All data except stock prices were provided by the staff of the ECB. For additional details on the data, see Fischer, Lenza, Pill and Reichlin (2007).

<sup>13</sup> The German stock-price index was obtained from the International Financial Statistics (IFS), line 62.

<sup>14</sup> Data for stock prices were downloaded from the Data Warehouse of ECB.

<sup>15</sup> For a discussion of these tests, see Maddala and Kim (1998, pp. 45-146). The linearity assumption made here is crucial for the VEC analysis in Section 3.1. It is not needed for the TVC analysis in Section 3.2 below.



money balances, real income, the ratio of real wealth to real income and the price level were included as I(1) variables in the VAR specification, while the spread between stock returns and own rate was included as I(0).<sup>16</sup>

### 3.1 VEC Results

Our point of departure for testing the causal relationship between money and prices is to estimate the dynamic structural money and price equations, we also allow for the endogeneity of income and wealth to income ratio. For this purpose a VAR system was constructed including four endogenous variables,  $m$ ,  $y$ ,  $w-y$ , and  $p$  as its dependent variables and five exogenous variables which are described below. Several of these exogenous variables were used in previous studies of money demand. In particular, as in Calza, Gerdesmeier and Levy (2001) and Fischer, Lenza, Pill and Reichlin (2007, Appendix), our VAR system included a constant and one quarter lagged changes in oil prices ( $\Delta oil_{t-1}$ ), in order to take account of the difficulty of fully capturing the impact of external developments on domestic prices (*i.e.*, on the GDP deflator) at times of rapid changes in imported oil prices.<sup>17</sup>

In addition to the above variables, our VAR specification includes the following four exogenous variables. (1) The spread between the rate of return on equities and the own rate of return on money, lagged one period. As noted above, this variable, which is I(0), is the relevant opportunity-cost variable within the context of the Brainard-Tobin framework. (2) A split trend (denoted as  $st1$ ), with a value of zero until 2001:Q4 and the (trend) values of one to nineteen for the period 2002:Q1 to 2006:Q3. This variable aims to capture both the physical introduction of the euro, beginning in 2002, and the rapid rise in housing wealth that occurred in many euro-area countries over the period 2002-2006. (3) Another split trend (denoted as  $st2$ ), with trending values of 1 to 25 for the period 1988:Q1 - 1994:Q1, values which decline by 5 units in each of the next five quarters (*i.e.*, through 1995:Q2), and values of zero otherwise. (4) A Hodrick-Prescott (HP) filter of the proxy for wealth to income (denoted as  $hp(w-y)$ ). The split trend,  $st2$ , aims to capture several shocks that impacted on European financial markets during 1988-95, including (a) the emergence of the “New EMS” in 1988, under which there were no currency realignments until 1992:Q3, (b) German unification in 1990, and (c) the crisis among

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<sup>16</sup> For a definition of I(0) or I(1), see Greene (2003, p. 631).

<sup>17</sup> This was the justification provided by Beyer, Fischer and von Landesberger (2007).

currencies in the EMS in late 1992 and in 1993.<sup>18</sup> Regarding the application of the HP filter to the ratio of the proxy for wealth to income, a comprehensive measure of wealth would include financial wealth, housing wealth, and other non-financial wealth. Were such a measure of wealth available, it would be expected to evolve more smoothly than any of its individual components. In the absence of such a comprehensive measure, the log of the ratio of wealth to income was smoothed using the HP filter, especially as our stock market variable is linked only to the German stock market for part of the period. Because transitory departures from this smoothed log ratio are expected to have some effect on money demand, both the variables,  $(w-y)$  and  $hp(w-y)$ , are included in the system. **The ADF, PP, and KPSS tests have shown that  $st1$ ,  $hp(w-y)$ , and  $st2$  are  $I(1)$  variables.**

To briefly summarize, in the absence of an all inclusive measure of wealth for the euro area, we used four variables to proxy the evolution of wealth: (1) the ratio of (real) euro-area stock prices to (real) income; (2) a one-period lagged HP filter of this variable, filtered because we would expect wealth to move more smoothly than stock-market prices; (3) a split trend ( $st1$ ) aimed at capturing, in part, the rise in housing wealth in many euro-area countries beginning in 2002; and (4) another split trend ( $st2$ ) that aims to capture the effects of several shocks in the late 1980s and early 1990s that may have affected the linkage between stock-market prices and euro-area wealth. In addition, because the spread between the rate of return on equities and the rate of return on money, which is in equation (1), was  $I(0)$ , its one-period lagged value only appears in the dynamic error-correction model, though it still has an effect on long-run money demand.

The next step in the estimation procedure involved VAR estimation, misspecification testing and tests for co-integration among the variables.<sup>19</sup> To determine the lag length of the VAR model, alternate versions of the system were initially estimated using different lags. An Akaike information criterion, a Schwartz Bayesian criterion, and a Hannan-Quinn criterion were used to determine the lag

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<sup>18</sup> The term “EMS” refers to the European Monetary System. Beginning in 1988, there were no realignments in the EMS until the crisis of 1992. This period of fixed central rates has been called the “new EMS” (Cobham, 1996). References to the EMS should be taken to refer to the currencies participating in the exchange-rate mechanism (ERM) of the EMS.

<sup>19</sup> For a discussion of this procedure of estimation and testing, see Maddala and Kim (1998, pp. 155-242).

length.<sup>20</sup> This procedure revealed that five lags should be used. Therefore, a VAR model of order five was used in the estimation procedure of co-integration.

The number of co-integrating relationships in the system was tested using the Johansen procedure (Johansen, 1995). This approach enables us (a) to determine the number of co-integrating vectors and (b) to identify and estimate the co-integrating vectors subject to appropriate specification testing. With four endogenous variables in equation (1) (money balances, real income, the ratio of real wealth to real income and price level), the Johansen procedure yields at most four co-integrating vectors. As shown in Table 1, both the tests based on maximum eigenvalue and trace **statistics** led to the rejection of the null of zero co-integrating vectors in favor of four such vectors at the 1 or 5 per cent level of significance.<sup>21</sup>

It is important to emphasize here that our model is not a closed VEC in the usual sense of Johansen (1988) where all the variables are treated as endogenous. Instead, here we have four I(1) variables ( $m_t$ ,  $y_t$ ,  $(w-y)_t$ ,  $p_t$ ) which we treat as endogenous and three I(1) variables ( $st1_t$ ,  $hp(w-y)_{t-1}$ , and  $st2_t$ ) which we treat as exogenous.<sup>22</sup> The system is thus analogous to that investigated by Davidson and Hall (1991). In a closed VEC involving  $n$  non-stationary variables there can be at most  $n-1$  co-integrating vectors (Greene, 2003, p. 652). However in a conditional VEC involving  $n$  (**unit-root**) non-stationary endogenous variables and some exogenous variables, there may be  $n$  co-integrating vectors as the non-stationarity may now be due to the exogenous variables.<sup>23</sup> Of **course**, if the co-integrating rank of the system is greater than 1, we have the problem that the co-integrating vectors are not identified and, thus, are not unique. This situation requires out-of-sample, *exact* information in the form of a formal set of identifying restrictions in order to obtain a unique set of vectors. Pesaran and Shin (2002) outline the basic rank and order conditions for

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<sup>20</sup> The correct model may not be of VAR type and in sample samples these criteria do not necessarily lead us to the correct model even assuming that it is among the VARs considered (Greene, 2003, p. 159).

<sup>21</sup> Both the null and alternative hypotheses considered for these tests can be false, since a restrictive VAR model is considered. Any test of a false null hypothesis against a false alternative hypothesis can only reject the false null hypothesis in favor of the false alternative hypothesis. In Section 3.2, this difficulty is avoided by considering an infinite class of models which are more general than VAR models.

<sup>22</sup> Here  $t$  indexes time.

<sup>23</sup> That is, in a closed system there can be no source of non-stationarity other than the interaction of the endogenous variables. In a conditional system, the non-stationarity may also be due to the trending exogenous variables.

identifying the co-integrating vectors uniquely. The basic order condition is that we require  $r^2$  restrictions for exact identification, where  $r$  is the co-integrating rank.

Thus, sixteen restrictions are needed to just identify the four vectors. The first co-integrating vector is used to form the portfolio balance relationship, the second the real income equation, the third the wealth to income ratio equation and the last the price equation. To see the exact formulation consider the following VEC system

$$\Delta \mathbf{m}_t = \theta_{11} [\mathbf{m}_{t-1} - \mathbf{z}'_{1,t-1} \theta_1] + \theta_{12} [\mathbf{y}_{t-1} - \mathbf{z}'_{2,t-1} \theta_2] + \lambda_{13} [(\mathbf{w}-\mathbf{y})_{t-1} - \mathbf{z}'_{3,t-1} \theta_3] + \lambda_{14} [\mathbf{p}_{t-1} - \mathbf{z}'_{4,t-1} \theta_4] + \mathbf{x}'_t \beta_1 + \varepsilon_{1t}; \quad (2)$$

$$\Delta \mathbf{y}_t = \theta_{21} [\mathbf{m}_{t-1} - \mathbf{z}'_{1,t-1} \theta_1] + \theta_{22} [\mathbf{y}_{t-1} - \mathbf{z}'_{2,t-1} \theta_2] + \lambda_{23} [(\mathbf{w}-\mathbf{y})_{t-1} - \mathbf{z}'_{3,t-1} \theta_3] + \lambda_{24} [\mathbf{p}_{t-1} - \mathbf{z}'_{4,t-1} \theta_4] + \mathbf{x}'_t \beta_2 + \varepsilon_{2t}; \quad (3)$$

$$\Delta (\mathbf{w}-\mathbf{y})_t = \lambda_{31} [\mathbf{m}_{t-1} - \mathbf{z}'_{1,t-1} \theta_1] + \lambda_{32} [\mathbf{y}_{t-1} - \mathbf{z}'_{2,t-1} \theta_2] + \lambda_{33} [(\mathbf{w}-\mathbf{y})_{t-1} - \mathbf{z}'_{3,t-1} \theta_3] + \lambda_{34} [\mathbf{p}_{t-1} - \mathbf{z}'_{4,t-1} \theta_4] + \mathbf{x}'_t \beta_3 + \varepsilon_{3t}; \quad (4)$$

$$\Delta \mathbf{p}_t = \theta_{41} [\mathbf{m}_{t-1} - \mathbf{z}'_{1,t-1} \theta_1] + \lambda_{42} [\mathbf{y}_{t-1} - \mathbf{z}'_{2,t-1} \theta_2] + \lambda_{43} [(\mathbf{w}-\mathbf{y})_{t-1} - \mathbf{z}'_{3,t-1} \theta_3] + \lambda_{44} [\mathbf{p}_{t-1} - \mathbf{z}'_{4,t-1} \theta_4] + \mathbf{x}'_t \beta_4 + \varepsilon_{4t} \quad (5)$$

where  $\mathbf{z}'_{1,t-1} = [\mathbf{y}_{t-1}, (\mathbf{w}-\mathbf{y})_{t-1}, \mathbf{p}_{t-1}, \mathbf{st1}_{t-1}, \mathbf{hp}(\mathbf{w}-\mathbf{y})_{t-2}, \mathbf{st2}_{t-1}]$ ,  $\mathbf{z}'_{2,t-1} = [\mathbf{m}_{t-1}, (\mathbf{w}-\mathbf{y})_{t-1}, \mathbf{p}_{t-1}, \mathbf{st1}_{t-1}, \mathbf{hp}(\mathbf{w}-\mathbf{y})_{t-2}, \mathbf{st2}_{t-1}]$ ,  $\mathbf{z}'_{3,t-1} = [\mathbf{m}_{t-1}, \mathbf{y}_{t-1}, \mathbf{p}_{t-1}, \mathbf{st1}_{t-1}, \mathbf{hp}(\mathbf{w}-\mathbf{y})_{t-2}, \mathbf{st2}_{t-1}]$ ,  $\mathbf{z}'_{4,t-1} = [\mathbf{m}_{t-1}, \mathbf{y}_{t-1}, (\mathbf{w}-\mathbf{y})_{t-1}, \mathbf{st1}_{t-1}, \mathbf{hp}(\mathbf{w}-\mathbf{y})_{t-2}, \mathbf{st2}_{t-1}]$ ,  $\Delta$  is the first-difference operator, the variables,  $\Delta \mathbf{m}_t = \mathbf{m}_t - \mathbf{m}_{t-1}$ ,  $\Delta \mathbf{y}_t = \mathbf{y}_t - \mathbf{y}_{t-1}$ ,  $\Delta (\mathbf{w}-\mathbf{y})_t = (\mathbf{w}-\mathbf{y})_t - (\mathbf{w}-\mathbf{y})_{t-1}$ ,  $\Delta \mathbf{p}_t = \mathbf{p}_t - \mathbf{p}_{t-1}$ ,  $\mathbf{x}'_t = [\Delta \mathbf{m}_{t-1}, \Delta \mathbf{m}_{t-2}, \Delta \mathbf{m}_{t-3}, \Delta \mathbf{m}_{t-4}, \Delta \mathbf{y}_{t-1}, \Delta \mathbf{y}_{t-2}, \Delta \mathbf{y}_{t-3}, \Delta \mathbf{y}_{t-4}, \Delta (\mathbf{w}-\mathbf{y})_{t-1}, \Delta (\mathbf{w}-\mathbf{y})_{t-2}, \Delta (\mathbf{w}-\mathbf{y})_{t-3}, \Delta (\mathbf{w}-\mathbf{y})_{t-4}, \Delta \mathbf{p}_{t-1}, \Delta \mathbf{p}_{t-2}, \Delta \mathbf{p}_{t-3}, \Delta \mathbf{p}_{t-4}, \Delta \mathbf{oil}_{t-1}, (r^e - r^m)_{t-1}]$ , and  $[\mathbf{m}_{t-1} - \mathbf{z}'_{1,t-1} \theta_1]$ ,  $[\mathbf{y}_{t-1} - \mathbf{z}'_{2,t-1} \theta_2]$ ,  $[(\mathbf{w}-\mathbf{y})_{t-1} - \mathbf{z}'_{3,t-1} \theta_3]$ ,  $[\mathbf{p}_{t-1} - \mathbf{z}'_{4,t-1} \theta_4]$  are  $I(0)$ ,  $[1, -\theta'_{11}]'$  is the corresponding co-integrating vector,  $[\mathbf{m}_{t-1} \theta'_{1,t-1} \theta_1]$ ,  $[\mathbf{y}_{t-1} \theta'_{2,t-1} \theta_2]$ ,  $[(\mathbf{w}-\mathbf{y})_{t-1} - \mathbf{z}'_{3,t-1} \theta_3]$ ,  $[\mathbf{p}_{t-1} \theta'_{4,t-1} \theta_4]$  are the error-correction terms (ECT) and the lambdas are their coefficients. Thus, each of the above equations of the VEC system has four error correction terms since there are four co-integrating vectors.<sup>24</sup>

<sup>24</sup> We estimated the VEC recursively to test for stability. The recursive estimates of the coefficients of  $\mathbf{m}$ ,  $\mathbf{y}$ ,  $\mathbf{w}-\mathbf{y}$ , and  $\mathbf{p}$  variables indicate that these coefficients are fairly stable over the estimation period.

We begin by testing the factors which may cause money. We will undertake a sequence of tests. First, we will test for absolute causality without imposing any structure or co-integrating rank. Next, we will test for absolute causality imposing a co-integrating rank but not identifying the structure. Finally, we will consider structural identification.

The first causality test is performed as a full weak exogeneity test without imposing any co-integrating rank. The null hypothesis that the levels of the seven of the I(1) variables are jointly significant in the money equation is tested. The likelihood ratio (LR) test is equal to 33.2 for 7 degrees of freedom (d.f.) which rejects the null at 1% level of significance.

Next, we test the hypothesis of weak exogeneity for money imposing the co-integrating rank of four. Specifically, the hypothesis tested is that the  $\lambda$  s are jointly equal to zero ( $\lambda_{11} = \lambda_{12} = \lambda_{13} = \lambda_{14} = 0$ ). This is formulated as a Wald test, which follows the F-distribution with 4 and 78 d.f. The estimated value of Wald test is equal to 8.77. Thus, the null hypothesis that money is weakly exogenous is rejected at the 1% level of significance. Next, we identified the structural relationships and we test for structural causality using the null that each of the error correction terms,  $\lambda$  s, in the money equation is equal to zero. The estimated t-statistic for the respective  $\lambda$  s are as follows: 5.81 for  $\lambda_{11}$ , -3.91 for  $\lambda_{12}$ , -0.01 for  $\lambda_{13}$ , and 0.88 for  $\lambda_{14}$ . Thus, only the first two structural relationships (portfolio balance and income relationship) are significant. The above causality tests indicate that money is not weakly exogenous to the other endogenous variables. The results also imply that the structural channel through which prices affect money is via the portfolio balance and income relationships.

We applied the identical testing procedure to the price equation. The likelihood ratio test of weak exogeneity without imposing any structure or co-integrating rank results in LR = 64.2 for d.f. = 7, which rejects the null at the 1% level of significance. The Wald test of weak exogeneity, imposing the co-integrating rank

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Specifically, the Chow's (1960) one-step-ahead, predictive failure, and break-point tests for all the equations and for the system of the unrestricted VEC were conducted. The results indicate that the system is stable. In addition, the constancy of the coefficients of the short-run money-demand equation (2) and price equation (5) were tested using the CUSUM and CUSUM of squares (CUSUMQ) tests. In general, there is no sign of parameter instability in the system or in the estimated short-run money-demand and price equations. These results are available from the authors upon request.

of four, gives the value of 20.39 to the test statistic. This rejects the null hypothesis that  $\lambda_{41} = \lambda_{42} = \lambda_{43} = \lambda_{44} = 0$  at the 1% level of significance. Hence, prices are not weakly exogenous. The estimated t-statistics for each of the identifying structural relationships are -0.38, -5.26, 8.82, -5.08 for  $\lambda_{41}$ ,  $\lambda_{42}$ ,  $\lambda_{43}$ , and  $\lambda_{44}$ , respectively. Thus, the null hypothesis is not rejected only in the case of the first structural relationship (portfolio balance equation). These results suggest that the conventional portfolio money demand relationship should not be inverted to derive a price equation.

In sum, for both money and prices we reject the hypothesis that all the  $\lambda$ s are zero. This indicates that neither money nor prices can be treated as weakly exogenous and that long run causality runs in both directions. Thus, money is not a fixed exogenous variable which is set to grow at an exogenous rate. Instead, the empirical results suggest that both money and prices are interacting in a complex way.

Further, the empirical results reveal structural causation. According to our formulation, structural causation can be viewed as the structural relationship among  $r$  co-integrating vectors. Specifically, if there is a set of  $r$  co-integrating vectors, and an identification scheme is accepted so that these vectors can provide a clear structural interpretation, then each of the structural relations could be considered as an attractor, and the  $\lambda$ s in each error-correction equation show whether each structural relationship has a direct causal relationship within that equation. In our empirical estimation, we found that the main determinant of money in the long run is the portfolio balance relationship and that this does not have a causal effect in the price equation. Therefore, money is being endogenously determined mainly by the portfolio balance relationship, but this does not feedback directly on prices. Money does, however, enter into the other relationships. Money is part of the pricing relationship and the other long run relationships which do cause prices. Thus, money influences prices through the pricing relationship and other relationships. The portfolio balance relationship is a useful indicator of the long run behavior of money and can be used to examine if money is above or below its equilibrium. Money then causes prices through the other structural relationships. The results support the view that a money demand function exists, but it does not cause prices. Instead other parts of the system provide the link from money to prices.

Overall the empirical results from the VEC estimation imply that money acts as an intermediate target in monetary policy rather than as an exogenous control variable. Thus, the money supply can be considered as a useful signal of inflationary pressures and as part of the transmission mechanism.

Let us now assess these results. Generally accepted meanings of ‘causality’ fails to involve the notion that causation is a real-world, invariant relation between events. As Basmann (1988, p. 99) has argued that causal relations are unique in the real world and they remain invariant against mere changes in the language we use to describe them. However in a structurally change environment the direction of causality might indeed. Equations (2) and (5) are the real-world, invariant relations between money and prices with causal implications if (i) their functional forms are correct, (ii) their coefficients and error terms are unique, (iii) their coefficients do not contain omitted-variable biases, (iv) our data on their variables do not contain measurement errors, (v) our assumptions about their error terms are appropriate, and (vi) the variables which we assume as exogenous are truly exogenous. If however any of these assumptions are false our results might be misleading, Pratt and Schlaifer (1984, 1988). For this reason, we relax all the assumptions underlying (2) and (5) in the next section.

### 3.2 TVC Results

The advantages of TVC estimation include that it is robust to the functional form specification and omitted-variable and measurement-error biases. The principles that natural, or intuitive, conceptions of causality include are clearly laid out by Basmann (1988, p. 73) and Granger(1969). It is clear that the outcomes of a causality tests depend on the choice of variables and functional forms. We, therefore, propose a generalization of the usual Granger causality framework by setting it within a TVC framework.

To examine the causal relationship between money and prices two dynamic equations are constructed. The first is a money equation and the second a price equation. To correct for misspecifications in (2) and (5), we specify the following two dynamic equations which are estimated using the TVC technology:

$$m_t = a_{10t} + a_{11t} m_{t-1} + a_{12t} p_{t-1} \quad (6)$$

$$p_t = a_{20t} + a_{21t} m_{t-1} + a_{22t} p_{t-1} \quad (7)$$

where, in both equations, the coefficients are time-varying.

We will now show that equations (6) and (7), though appear to be false with a large number of omitted variables, can tell us a lot about the causal relations between money and prices if their coefficients are correctly interpreted. The coefficients with the correct interpretations are unique, as shown by Swamy and Tavlas (2007, p. 300, Proposition 3). This uniqueness property is not possessed by the coefficients and the error terms of equations (2) and (5), as the arguments of Pratt and Schlaifer (1984, 1988) show. Those coefficients and values of error terms that are facts about the real world are unique (Pratt and Schlaifer, 1984, p. 13). Thus, the coefficients of (6) and (7) share the property of uniqueness with the real-world coefficients and error terms when they are correctly interpreted.

Equation (6) is a dynamic money equation and equation (7) is a dynamic price equation. These equations which are linear in variables are nonetheless non-linear, since their coefficients are allowed to have non-linear time profiles. Thus, the linearity assumption made in Section 3.1 is relaxed. It follows from the derivation in Swamy and Tavlas (2007, p. 301) that the determinants of  $m_{t-1}$  are the same as those of  $m_t$  in period  $t-1$ . The variable  $p_{t-1}$  could be one of the determinants of  $m_{t-1}$ . The correlation between  $m_t$  and  $m_{t-1}$  introduces a component into  $a_{11t}$ . This component represents a spurious correlation. If there are new determinants of  $m_t$  in period  $t$  that were not present in the previous periods, then the regression of each of these new determinants on  $m_{t-1}$  and  $p_{t-1}$  gives the components of  $a_{11t}$  and  $a_{12t}$  that can be called “the omitted-variables bias components”. These components change as the two- and longer-period lagged values of  $m_t$  and  $p_t$  are included on the right-hand side of (6).

If our data on  $m_{t-1}$  and  $p_{t-1}$  contain measurement errors, then  $a_{11t}$  and  $a_{12t}$  contain additional components that can be called “the measurement-error bias components”. These components also change as the number of the lagged values of  $m_t$  and  $p_t$  included on the right-hand side of (6) increases. The measurement-error bias components introduce correlations between  $m_{t-1}$  (or  $p_{t-1}$ ) and  $a_{11t}$  (or  $a_{12t}$ ).



If  $p_{t-1}$  is not one of the determinants of  $m_{t-1}$ , then the direct effect of  $p_{t-1}$  on  $m_t$  appears as a component of  $a_{12t}$  that is different from the  $a_{12t}$ 's omitted-variable and measurement-error bias components. We call this direct effect “a causal effect or bias-free component”. If  $p_{t-1}$  is one of the determinants of  $m_{t-1}$ , then equation (6) has no causal implications.

The intercept,  $a_{10t}$ , is the sum of (i) the measurement error in  $m_t$ , (ii) the effect on the true value of  $m_t$  of the portions of the true values of excluded variables remaining after the effects of the true values of  $m_{t-1}$  and  $p_{t-1}$  have been removed, and (iii) the true intercept of (6).

The interpretations of the coefficients of equation (7) are analogous to those of (6). Thus, unlike the VEC analysis in Section 3.1, the analysis of this section does not ignore omitted-variable and measurement-error biases. Their components are the real-world sources of variation in the coefficients of (6) and (7). These coefficients cannot be constants if their components are variables. This shows that the inaccrancies in the constancy condition on the coefficients of models (2)-(5) are obscured by the fact that the omitted-variables and measurement-error bias components of those coefficients are ignored. There are no exogenous variables in (6) and (7) so that the question of whether our exogenous assumptions are correct does not arise. One of the important implications of equations (6) and (7) is that  $m_t$  and  $p_t$  do not become stationary if they are first differenced any number of times and the classification of  $m_t$  and  $p_t$  as I(1) variables in Section 3.1 is the result of the incorrect linear functional form of the VAR model. This can be seen by taking the first differences of both sides of equations (6) and (7).

It is assumed that for  $i = 1, 2$  and  $j = 0, 1, 2$ :

$$a_{ijt} = \pi_{j0} + \pi_{j1} z_{1t} + \dots + \pi_{jp} z_{pt} + \varepsilon_{jt} \quad (8)$$

where the  $\pi$ 's are constants, the  $\varepsilon_{jt}$  are contemporaneously and serially correlated as in Swamy and Tavlas (2001, p. 419), and the  $z$ 's are the coefficient drivers. Since the coefficients of (6) and (7) are not unconditionally independent of  $m_{t-1}$  and  $p_{t-1}$ , it is assumed that they are conditionally independent of  $m_{t-1}$  and  $p_{t-1}$  given the coefficient

drivers. This conditional independence can be true even though the unconditional independence is false. Under assumption (8), TVC models (6) and (7) give fixed-coefficient models with more than one heteroscedastic and serially correlated error term when equation (8) is substituted into equations (6) and (7).<sup>25</sup>

The most difficult step in our TVC approach is the choice of coefficient drivers. Eight coefficient drivers were used:  $hp(w-y)_{t-1}$ , one-period lag of  $\Delta(m-p)_t$ , one-period lag of  $\Delta y_t$ , one-period lag of  $\Delta(w-y)_t$ , one-period lag of  $\Delta p_t$ ,  $\Delta oil_{t-1}$ , and  $(r^e - r^m)_{t-1}$ , and the constant term. Effectively, these coefficient drivers can be viewed as capturing the effects of specification errors, including omitted variables.

For  $j = 1, 2$ ,  $a_{ijt}$  is treated as a total coefficient while a portion of  $a_{ijt}$  as a bias-free component. This latter portion is defined as  $\sum_{k \in S_1} \pi_{jk} z_{kt}$ , where  $S_1$  is a subset of  $\{0, 1, \dots, p = 7\}$ . That is, to derive the total-effect coefficients, we used the seven variables employed in the VEC specification, plus the constant term. Next, to identify the bias-free component, we needed a subset of eight coefficient drivers, one of which is the constant term. We settled on a subset of three coefficient drivers to identify the bias-free component: the constant term,  $hp(w-y)_{t-1}$ , and  $(r^e - r^m)_{t-1}$ .<sup>26</sup>

The bias-free components do not represent causal effects if they are the portions of the coefficients of lagged dependent variables. The bias-free components of  $a_{11t}$  and  $a_{22t}$  of (6) and (7), respectively, represent the effects of some of the determinants that are common to both the corresponding dependent variable and its lagged value -- in common parlance, a 'common cause'. *The variables,  $hp(w-y)_{t-1}$  and  $(r^e - r^m)_{t-1}$ , we chose to measure the bias-free components are some of the variables that effect both  $m_t$  and  $m_{t-1}$ . The bias-free components of  $a_{12t}$  and  $a_{21t}$  of (6) and (7) measure causal effects if  $p_{t-1}$  and  $m_{t-1}$  are not the determinants of  $m_{t-1}$  and  $p_{t-1}$ , respectively.*

Table 2 presents both the total coefficients and the bias-free components for the money equation. The coefficient on lagged money and its bias-free component are

<sup>25</sup> For detailed discussions, see Swamy and Tavlas (2001, 2007).

<sup>26</sup> Other subsets of coefficient drivers yielded very similar results.

significant while the coefficient on lagged price and its bias-free component are not. Table 3 presents both the total coefficients and bias-free components for the price equation. The coefficients on lagged money and lagged price and their bias-free components are all significant. If these estimates are accurate and  $p_{t-1}$  and  $m_{t-1}$  are not the determinants of  $m_{t-1}$  and  $p_{t-1}$ , respectively, then they support the proposition that causation runs from money to inflation and not vice versa.

These results suggest that money is indeed acting as an exogenous process determining the price level. This contrast with the results from the VEC estimation in which causation runs in both directions. The contrasting results leave an open question as to the true role of money in the economy. The conflict is may be due to the ability of TVC approach to deal with underlying misspecification in the VEC model or it may be that the greater structural specification of the VEC model is allowing us to obtain more accurate results in such a small sample.

#### **4. Conclusions**

Using two different estimation techniques, VEC and TVC, we investigated the causal relationship between money and price in euro- area employing quarterly data for the period 1980 to 2006. Employing the first technique, we were able to construct a dynamic system which includes four underlying structural relationships and test for all possible linkages between money and prices. The empirical results from the VEC estimation suggest the existence of possible bidirectional causality between the two variables. It also suggested that money was mainly driven by the portfolio balance relationship which typically underlies discussion of the demand for money while prices were driven by pricing and output relationships which also included money. We were therefore able to give our results an interesting economic interpretation as to the channels through which money and prices are related

The VEC methodology relies heavily on some strong assumptions regarding linearity, correct specification and the absence of unmodeled structural change and measurement error. We therefore turned to TVC estimation to provide a straightforward method of addressing these problems. Our results in this section suggest that money is acting as an exogenous process determining the price level. This result is quite different from the VEC result. However it is important to

understand the nature of what the TVC approach is trying to do. It is attempting to find an unbiased estimate of the effect of one lag of prices on money. If in fact there is a long delay in the response of money to prices and the main effect comes after 3 or 4 periods then we may correctly find no effect from the first lag and incorrectly conclude that there is no effect at all. This is an issue for further research.

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**Table 1**

<b>Johansen Co-integration Tests</b>				
<b>Long-Run Demand for Money in Euro Area: Sample 1980:Q1-2006:Q3</b>				
VAR of order 5, Variables: m, y, (w-y), p and five exogenous variables				
<i>Maximum Eigenvalue</i>				
Null	Alternative	Eigenvalue	Critical Values	
			95%	99%
r=0	r=1	75.52***	27.58	32.72
R<=1	r=2	44.74**	21.13	25.86
R<=2	r=3	32.90***	14.26	18.52
R<=3	r=4	12.38***	3.84	6.63
<i>Trace Statistic</i>				
Null	Alternative	Trace	Critical Values	
			95%	99%
r=0	r>=1	165.55***	47.86	54.68
r<=1	r>=2	90.02***	29.80	35.46
r<=2	r>=3	45.29***	15.49	19.94
r<=3	r>=4	12.38***	3.84	6.63

*Note:* r indicates the number of co-integrating relationships. The maximum eigenvalue and trace statistic tests are compared with the critical values from Johansen and Juselius (1990). \*\*, \*\*\* indicates rejection of the null hypothesis at the 5 and 1 per cent level.



<b>Table 2</b>		
<b>TVC Estimation of Long-Run Money for Euro-area</b>		
Variables	Total effects	Bias-free effects
	(1)	(2)
Constant	-0.133 [-0.94]	-0.347*** [-1.21]
M(-1)	1.037*** [31.37]	1.074*** [20.12]
P(-1)	-0.090 [-1.20]	-0.167 [-0.34]
$\bar{R}^2$	0.99	0.99

*Notes:* Figures in brackets are t-ratios. \*\*\* indicates significance at 1% level. The estimates in columns (1) are obtained using as coefficient drivers: one lag of the first difference of, nominal money, real income, wealth to income and price, one lag of HP filter of wealth to income ratio, one lag change in oil prices and the lag of the spread between stock returns and own rate of M3. The bias-free effects are estimated using three coefficient drivers: constant term, one lag of HP filter of wealth to income ratio and the lag of the spread between stock returns and own rate of M3.

<b>Table 3</b>		
<b>TVC Estimation of Long-Run Price Equation for Euro-area</b>		
Variables	Total effects	Bias-free effects
	(1)	(2)
Constant	-0.260*** [-3.78]	-0.819*** [-5.13]
M(-1)	0.056*** [3.59]	0.147*** [4.92]
P(-1)	0.872*** [23.34]	0.695*** [10.83]
$\bar{R}^2$	0.99	0.99

*Notes:* Figures in brackets are t-ratios. \*\*\* indicates significance at 1% level. The estimates in columns (1) are obtained using as coefficient drivers: one lag of the first difference of, nominal money, real income, wealth to income and price, one lag of HP filter of wealth to income ratio, one lag change in oil prices and the lag of the spread between stock returns and own rate of M3. The bias-free effects are estimated using three coefficient drivers: constant term, one lag of HP filter of wealth to income ratio and the lag of the spread between stock returns and own rate of M3.