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Sophocles N. Brissimis
George Hondroyiannis
P.A.V.B. Swamy
George S. Tavlas

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BANK OF GREECE
Economic Research Department – Special Studies Division
21, ? . Venizelos Avenue
GR-102 50 ? thens
? el: +30210-320 3610
Fax: +30210-320 2432

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# EMPIRICAL MODELLING OF MONEY DEMAND IN PERIODS OF STRUCTURAL CHANGE: THE CASE OF GREECE

Sophocles N. Brissimis
Bank of Greece, Economic Research Department and University of Piraeus

George Hondroyiannis
Bank of Greece, Economic Research Department

P.A.V.B. Swamy
US Bureau of Labour Statistics

George S. Tavlas
Bank of Greece, Economic Research Department

**ABSTRACT**

This paper examines the behaviour of the demand for money in Greece during 1976:1-2000:4, a period that included many of the influences that cause money-demand instability. Two empirical methodologies, vector error correction (VEC) modelling and second-generation random coefficient (RC) modelling, are used to estimate the demand for money. The coefficients of both the VEC and RC procedures support the hypothesis that the demand for money becomes more responsive to both the own rate of return on money balances and the opportunity cost of holding money because of financial deregulation. In general, both procedures also support the hypothesis that the income elasticity of money demand declines over time as a result of technological improvements in the payments system and the development of money substitutes, which lead to economies of scale in holding money.

*Keywords:* Money demand; VEC, random coefficient estimation
*JEL classification*: C20; E41

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**Correspondence:**
George Tavlas,
Economic Research Department,
Bank of Greece, 21 El. Venizelou St.,
102 50 Athens, Greece,
Tel. +30210-320.2370, Fax +30210-320.2432
Email: gtavlas@bankofgreece.gr

# 1. Introduction

The relation between the demand for money and its determinants is an essential component in most theories of macroeconomic behaviour. The empirical properties of the money-demand function, including its predictability and interest-rate and income elasticities, provide critical inputs in the formulation of monetary policy in many countries. Yet, empirical studies of money demand have had to confront such challenges as institutional changes, policy reversals, and regime changes, which have led to large forecasting errors and cast doubt about the usefulness of empirical money-demand models.[1]

This paper estimates the demand for money in Greece. The Greek context provides a substantial challenge for empirical models of money demand. The past twenty-five years in Greece have seen many of the circumstances that typically provide the greatest difficulty for money-demand estimation. There has been widespread innovation and a transition from a highly regulated to an unregulated financial system. There has also been a transition from profligate macro policies and high inflation (i.e., between 20 and 30 per cent) for much of the period to tight policies and inflation in the low single digits. The capital account has been opened. Monetary policy has switched from use of a narrow monetary aggregate as the main intermediate target, to a broad aggregate and, ultimately, to an exchange rate target.

The foregoing factors are likely to have caused changes in the responsiveness of the demand for money to its main determinants. To examine the evolution of Greek money demand, this paper applies two empirical methodologies - - second-generation random coefficient (RC) modelling and vector error correction (VEC) modelling. Second-generation RC models estimate time-varying coefficients and relax several key restrictions often imposed in empirical estimation.[2] Thus, they can help explain the evolution of the demand for money given the structural changes in the Greek economy. VEC modelling addresses problems of spurious correlation produced by unit-root nonstationarities variables and dynamic misspecification due to inadequate lag structure, and attempts to integrate short-run dynamics

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[1] Surveys of the empirical money-demand literature include Goldfeld (1992), Laidler (1993), Thompson (1993) and Sriram (2001).

[2] Swamy and Tavlas (1995; 2001) distinguish between first-generation and second-generation random coefficient models. The former are strictly concerned with relaxing the assumption of constant coefficients, usually in a mechanical manner. The latter have focused on providing realistic rationale for relaxing several additional assumptions typically made in classical estimation.

with departures from long-run equilibrium relationships.[3] The aim of this paper is to use both methodologies to investigate the behaviour of money demand under conditions that are likely to have significantly impacted on that behaviour.

The remainder of this paper is organized into five sections. To provide context, Section 2 briefly reviews salient features of the Greek financial environment during the past twenty-five years and offers hypotheses about how changes in that environment might have affected the relationship between money demand and its determinants. Section 3 presents the theoretical model. Although recent empirical work on money demand in Greece has focused on the behaviour of the narrower aggregates (Karfakis (1991), Psaradakis (1993), and Papadopoulos and Zis (1997)), the monetary aggregate used for estimation in this paper is M3, which served as the main aggregate guiding the conduct of monetary policy for much of the period under consideration. Section 4 describes the estimation procedures. Section 5 presents the empirical results. The theoretical model is estimated using VEC and RC with quarterly data over 1976:1 – 1997:4 and post sample forecasts are generated over 1998:1 – 2000:4, a period which saw a change in policy regime (discussed below) and a sharp acceleration in M3 growth because of the elimination of a withholding tax on repurchase agreements (repos).[4] The time-profiles of the VEC and RC coefficients are presented and discussed in light of the structural changes that took place during the estimation period. Section 6 concludes.

## 2. Structural changes: Implications for money demand

In what follows a brief overview of the Greek economic and financial system during 1976-2000 is provided in terms of (1) financial deregulation, (2) inflation performance and (3) the targets of monetary policy.[5] The implications of changes in the financial system and financial stability for the parameters of the money-demand function are discussed.

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[3] Sriram (2001) reviews the empirical work on money demand based on VEC modelling.

[4] Goldfeld (1992, p. 623) argued that: "Ultimately, of course, such [money-demand] models need to stand the forward test of time; that is the need to continue to hold outside the period of estimation." For a similar view, see Friedman and Schwartz (1991). Christou, Swamy and Tavlas (1998) provide a formal analysis of the use of out-of-sample predictability as a criterion for model evaluation.

[5] This discussion focuses on key changes in the economic and financial environment that might bear directly on money-demand behaviour. A detailed analysis of these and other issues is provided in Garganas and Tavlas (2001).

*2.1 Financial deregulation*

In the 1970s and early 1980s, the financial system was tightly regulated. Interest rates were administratively set, compulsory investment requirements for banks channeled funds into priority sectors of the economy at subsidized interest rates (including the monetary financing of the government at below-market rates), and restrictions were placed on capital outflows. Beginning around 1987, a series of deregulation measures improved the functioning of financial markets, allowing the increased use (in the 1990s) of indirect instruments of monetary control (i.e., open market operations, a rediscount facility, and reserve requirements). Financial liberalization was accompanied by the lifting of foreign exchange controls, with the last vestige of capital controls removed in May 1994. Essentially, by 1995 financial deregulation had been completed.

*2.2 Inflation regimes*

The past quarter century has witnessed three major inflation peaks, in 1979-80, 1985-86, and again in 1990 (Figure 1a). In each instance, inflation rose to at least 20 percent. Underlying the high rates of inflation were large government deficits. The general government deficit-to-GDP ratio averaged about 11 percent during 1981-94 (Figure 1b). The deficits were mainly financed by money creation, which provided seigniorage revenues. Beginning around 1994-95, a policy regime change occurred[6]. Monetary policy was sharply tightened as real short-term interest rates rose above the 5 percent level; real rates stayed above that level for most of the remaining years of the 1990s. Fiscal policy was progressively tightened; the deficit-to-GDP ratio fell to 0.9 percent in 2000, from over 10 percent in 1995 (Figure 1b). Inflation declined sharply, reaching about 3 percent in 2000 (Figure 1a)[7].

*2.3 Monetary policy*

Monetary targets were first announced (for M0) in 1975. In 1983, the Bank of Greece began placing emphasis on M3, which remained the main intermediate target until 1995

[6] Statistical evidence of a regime change in the inflation process around 1994-95 is presented in Garganas and Tavlas (2001). Contributing to the regime change was the enactment of a law granting independence to the central bank. Although not passed by Parliament until December 1997, the impending legislation had been signalled to the markets well in advance.

[7] The fall in inflation during 1995-2000 occurred against the backdrop of a steady acceleration of real growth. For the six years (i.e., 1995-2000), real GDP growth averaged over 3 percent, compared with 1.2 percent in the preceding five years.

(Figure 1c). During 1976-94, the targets for the monetary aggregates were often exceeded and monetary growth was at rates that were inconsistent with reasonable price stability.[8] In 1995 the Bank adopted a "hard drachma policy," under which the exchange rate was used as a nominal anchor. Although the Bank had previously (since the late 1980s) aimed to set a rate of depreciation of the drachma that did not fully accommodate inflation differentials between Greece and the country's main trading partners, the targets were implicit and subsidiary to the M3 target. In 1995, the exchange rate target became explicit and took precedence over the M3 target.[9] With the lifting of controls on capital flows and the adoption of an explicit exchange rate target, during the period 1995-2000 the Bank of Greece had to deal with large capital inflows and occasional, but sharp, reversals of these flows. In March 1998, the drachma was devalued (by 12.3 percent against the ECU) and joined the Exchange Rate Mechanism (ERM) of the European Monetary System (EMS). With the adoption of the euro by eleven EMS members on January 1, 1999, the drachma began participating in ERM II, with a standard fluctuation band of ± 15 percent.[10]

*2.4 Implications for money demand*

The economic and financial environment presented a variety of influences that often caused money demand instability. As shown in Figure 1d, the income velocity of M3 appears to have been characterized by considerable changes during 1976-2000.

Financial deregulation in Greece, as elsewhere, has resulted in the availability of more money substitutes paying competitive rates of return and the availability of increasingly-competitive rates of return on money balances. Other things remaining equal, the interest-rate elasticity of money demand, both with respect to the own rate (positive sign) and the rates on money substitutes (negative sign), should have risen in absolute value over time (Keely and Zimmerman (1986), Bordo and Jonung (1987, pp. 17-18), Tseng and Corker (1991)). To the extent that a measure of expected inflation is used as a proxy for the opportunity cost of

[8] For example, M0 growth averaged 18 percent in the years (1975-82) during which it served as the targeted aggregate. M3 growth averaged 24 percent in the first seven years (1983-89) following the decision to place greater emphasis on that aggregate. M0 is currency in circulation. M3 is defined in Section 3.2 below. One factor often cited in the Bank's *Annual Reports* as accounting for the difficulty in controlling money growth was the apparent instability in the demand for the aggregates.

[9] Intermediate targets for M3 growth continued to be announced through 1998. Dellas (1999) uses a dynamic, general-equilibrium, two-country model to assess the implications of alternative monetary-policy strategies in the case of Greece.

holding money, the (negative) coefficient on the expected-inflation variable should have increased in absolute value over time.[11]

Financial development is usually considered to decrease the income elasticity of the demand for money (Laidler (1971), Bordo and Jonung (1987, p. 149), Thomas (1993, p. 367). Such factors as technological improvements in the payments system and the development of money substitutes lead to economies of scale in holding money. In this regard, Bordo and Jonung, (1987, p. 14) interpret the empirical evidence as showing that "the [income] elasticity overtime appears to decline to close to unity in the postwar period".[12] Also, improved economic stability, measured, for example, by a decline in the level and volatility of the inflation rate, can be expected to decrease the income elasticity of money (Bordo and Jonung (1987, p. 149)).

Another possible influence on the income elasticity of money demand concerns wealth. Financial liberalization typically leads to balance-sheet expansion, with a rise in the financial wealth-to-income ratio. Because of data limitations, a financial wealth variable is not considered as a scale variable in this paper. However, it is important to note that the exclusion of such a variable when the wealth-to-income ratio is rising can influence the income elasticity of money demand. Assuming that the elasticity of money demand with respect to wealth is less than the elasticity with respect to income, an increase in the wealth-to-income ratio would produce a fall in the estimated income elasticity.

The possibility of changed elasticities over the sample period, in response to such factors as financial deregulation and financial development, suggests that, as Goldfeld and Sichel (1990, p. 322) have argued, any specification "which constrains the elasticity to be constant over the sample period may be inappropriate". In Section 4, we discuss an empirical approach that relaxes the constant-coefficient restriction.

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[10] Greek convergence efforts culminated in Greece's participation in the euro area, beginning on January 1, 2001.

[11] The expected inflation rate has been used as a determinant of the demand for money in situations where controls exist in financial markets. In such situations, published interest rates do not reflect the proper opportunity cost of holding money. See Bordo and Jonung (1987, p. 16).

[12] Bordo and Jonung (1987;1990) provide evidence showing that the inclusion of institutional variables in velocity functions reduces the income elasticity of the demand for money.

# 3. The model and data

*3.1 The model*

Theories of the demand for money attempt to explain one or more of the characteristics of money, stressing in particular the role of money as a transactions means and as an asset. In Greece, the main alternatives to holding money balances have been Treasury bills and real assets. Assuming that the asset choices of investors involve money (M), Treasury bills, and real assets, the demand for real money balances can be written as follows:

$$m - p = f\left(\overset{+}{\mathrm{y}}, \overset{+}{\mathrm{r}^{\mathrm{m}} - \Delta \mathrm{p}^{\mathrm{e}}}, \overset{-}{\mathrm{r}^{\mathrm{t}} - \Delta p^{\mathrm{e}}}\right) \qquad (1)$$

where $m$ is the log of M3, $\mathrm{p}$ is the price level, y is the log of real income, $\mathrm{r}^{\mathrm{m}}$ is the (nominal) own rate of return on money, $\Delta \mathrm{p}^{\mathrm{e}}$ is the expected inflation rate, and $\mathrm{r}^{\mathrm{t}}$ is the T-bill rate. Lower-case letters denote logarithms except for the rates of return variables. In equation (1), real rates of return are approximated by nominal rates minus the expected inflation rate and the (nominal) rate of return on real assets is represented by the expected inflation rate.[13]

We further assume rate of return homogeneity of degree zero, implying that, if all rates of return change by x percent, real quantities of all assets in investors' portfolios relative to real income will change equiproportionately. Thus, only rates-of-return differentials affect money demand. As a numeraire we use M. The money demand function, written in a particular linear form form, becomes:

$$(m - p)_t = d_0 + d_1 y_t + d_2 \left(r^t - r^m\right)_t + d_3 (r_t^m - \Delta p_{t+1}^e) + u_t \qquad (2)$$

where $d_1, d_3 > 0$ and $d_2 < 0$.

or, using $\Delta \mathrm{P}_t$ as a proxy for the expected inflation rate,

$$(m - p)_t = d_0 + d_1 y_t + d_2 \left(r^t - r^m\right)_t + d_3 r_t^m + d_4 \Delta p_t + u_t \qquad (3)$$

where $d_4 < 0$.

The empirical implementation of equation (3) in the case of Greece entails several practical problems having to do with the previously regulated financial system. T-bills were not available to the public until 1985 and holdings of such instruments were not appreciable

[13] This implicitly assumes that the real rate is zero. Alternatively, we could assume that the real rate of return on real assets is constant being subsumed in the constant term of the equation.

until 1990. Also, government bonds were sold beginning in 1990 and holdings of these bonds were modest until 1994.[14] Evidently, after the introduction of these instruments a period of adjustment was needed for economic agents to become familiar with them. In order to account for this factor with respect to T-bills, both a shift dummy and a slope dummy were used. With regard to the slope dummy, the interest rate differential between T-bills and the own rate on money was multiplied by a dummy which takes the value of unity beginning in 1990 (and zero prior to 1990). With regard to the interest rate on government bonds, we did not have sufficient observations to include this variable in the regressions. To account for its impact, a shift dummy, with a value equal to unity beginning in 1994:1 (and zero prior to 1994), was used in VEC estimation. Thus, a total of three dummy variables (two shift dummies and a slope dummy) were used in VEC estimation. RC estimation is intended to confront the effects of structural shifts produced by such factors as the introduction of new financial instruments. Accordingly, a shift dummy was not introduced into RC estimation.

*3.2 The data*

The following data were used. (The source of all data is the Bank of Greece.)

1. M3 is comprised of currency, demand deposits, savings deposits, time deposits, repurchase agreements, and bank bonds (one-year instruments issued by specialized financial institutions).

2. An official quarterly series on GDP at constant market prices is not available over the sample period (i.e., 1975:1-2000:4). Accordingly, we estimated a quarterly series on the basis of annual national accounts data, disaggregated by sector of economic activity, and the seasonal pattern of related indicators, which are available on a quarterly basis.

3. For the opportunity cost variable, the 12-month T-bill rate was used. The own rate on M3 is the weighted average of interest rates (net of withholding tax) on the various components of M3. As discussed below, a deposit rate and the level of industrial production were used in the RC model. Before 1988, the deposit rate is the maximum rate offered by commercial banks on three-to-six-month drachma time deposits by individuals and enterprises. Beginning in 1988, data refer to deposits with a maturity of three to twelve months.

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[14] Prior to the introduction of these financial instruments, real assets constituted the major alternative investment outlet.

4. The industrial production variable is the general index of total industrial production (1993=100).

5. The price variable is the consumer price index (1994=100).

## 4. Estimation methods

*4.1 VEC estimation*

An objective of VEC is to test for the existence of a long-run equilibrium, or cointegrating, relationship among the variables in equation (3). If such a relationship is found to exist, it is augmented with lagged differences of these variables and other stationary variables that economic theory may suggest as belonging in equation (3) in an attempt to capture the short-run dynamics of the variables in the system.[15] Standard methodology employs a three-step procedure (see, for example, Enders, (1995)). In the first step, the variables are tested for stationarity using Augmented Dickey-Fuller (ADF) tests. The second step involves VAR estimation and mispecification testing and tests for cointegration among the integrated variables. In this paper, the Johansen (1991) maximum likelihood procedure is used. The Johansen procedure tests for the significance of all the cointegrating vectors between the variables. Two tests are used to evaluate the number of cointegrating relationships: the trace test and the maximum eigenvalue test. With four endogenous variables (in equation (3)), the Johansen procedure yields at most three cointegrating vectors. This procedure treats all the variables included in equation (3) as endogenous, thus avoiding an arbitrary assumption of exogeneity. It provides a unified approach for estimating and testing cointegrating relations within the framework of a VEC model. Provided that one or more cointegrating relationships exist, the third step of the standard procedure involves the estimation of a VEC specification containing the cointegrating relationship(s), lagged first differences of the variables in the cointegrating relationship(s), and any stationary variables thought to influence money demand. Since this third stage depends on the outcomes of the tests conducted in steps 1 and 2, preliminary testing biases arise. These biases can lead to incorrect conclusions as shown by Greene (2000, pp. 292, 341).

[15] Some authors (e.g., Hafer and Jansen (1991); Hoffman and Rasche (1991, 1996); Hoffman, Rasche and Tieslau (1995)) have used cointegration to examine long-run elasticities in a money demand relation, without great concern for the short-run dynamics.

*4.2 RC estimation*

Standard estimation procedures often impose a number of restrictions when applied to equations such as equation (3) above, including the following[16]: (i) $\delta_0$, $\delta_1$, $\delta_2$, $\delta_3$, and $\delta_4$ are constants; (ii) the net effect of excluded explanatory variables is represented by an additive error term and, therefore, this net effect is assumed to have mean equal to zero and to be mean independent of the included explanatory variables; (iii) the true functional form is known (whether linear or non-linear); and, (iv) the included explanatory variables are not subject to measurement error. Restrictions (iii) and (iv) cannot be correct in practice and their correct version contradicts restrictions (i) and (ii).

To explain, consider the following realistic situation: the true functional forms of economic relationships are unknown and the economic data contain measurement errors. These conditions are the correct versions of restrictions (iii) and (iv), respectively. These versions show that the additive error term (the assumption of an additive error is itself misleading) in equation (3) is a function of the difference between the specified functional form and the true functional form and the measurement errors contained in the included explanatory variables. In these circumstances, the property of the additive error term violates restriction (ii), since the error term cannot have mean zero and cannot be mean-independent of the included explanatory variables. As shown below, it also violates restriction (i). Thus, if equation (3) contains contradictory restrictions, it cannot coincide with the true money-demand function.

Swamy and Tavlas (1995, 2001) and Chang *et al*. (2000) define as true (i) any economic relationship with the correct functional form, without any omitted explanatory variables, and without incorrectly measured variables. Using this definition, we can specify a class of functions, which is wide enough to cover the true money-demand function (in the sense of definition (i) as a member). To rewrite this class in a form that has the same explanatory variables as equation (3), we assume that explanatory variables that are in the true money-demand function, but excluded from equation (3), are related linearly or nonlinearly to the explanatory variables included in equation (3). This assumption is reasonable, given that economic variables are rarely, if ever, uncorrelated and may not be linearly related to each

[16] Courakis (1978) provides an assessment of the assumptions used to translate theoretical money-demand models, which may not be well specified, into empirical counterparts, which are based on “often *ad hoc* statistical assumptions” (1978, p. 537).

other. To account for measurement errors, we assume that the observations on each variable in equation (3) are the sums of “true” values and measurement errors.

How does RC estimation (RCE) utilize these assumptions to eliminate the foregoing four contradictory restrictions? We would like to specify a model that approximates closely the underlying true economic relationship. Following Swamy and Tavlas (2001) and Chang *et al*. (2000), our specified model can only coincide with the underlying true relationship if: (1) each of its slope coefficients is the sum of three terms - - a bias-free effect, an ommited-variables bias, and a measurement error; and (2) its intercept is the sum of three terms - - the true intercept, the measurement error in its dependent variable, and a combination of the intercepts of the relationships between the included and excluded explanatory variables. With regard to the coefficients on included explanatory variables, the bias-free effect components of these coefficients are the coefficients that would be observed if (i) there were no measurement errors, (ii) there were no omitted variables biases, and (iii) the specified functional form was true. The omitted-variables bias terms arise due to the fact that the true values of included explanatory variables affect those of excluded explanatory variables, which, in turn, influence the true value of the dependent variable. The measurement-error biases effects are due to errors in the measurement of the included explanatory variables. From these interpretations it follows that equation (3) can coincide with the true money demand function only if the coefficients on its included explanatory variables are time-varying. The sum of the intercept of equation (3) and $u_t$ is also time-varying, since it is equal to a sum of three time-varying terms.

As discussed above, to capture short-run dynamics, VEC estimation augments long-run equilibrium relationships with lagged differences of variables. To help capture the dynamics under RC, we assume lagged adjustment of actual money balances to desired balances occurs; only some fraction of the desired adjustment is accomplished in any one period and this fraction is time varying. Algebraically,

$$(m-p)_t - (m-p)_{t-1} = l_t[(m-p)_t^* - (m-p)_{t-1}] \qquad (4)$$

where the coefficient of adjustment $\lambda_t$, is time dependent and varies within a finite interval. Also, as RC estimation accounts for the effects of omitted variables, the effects of any omitted dynamic factors can be captured in the omitted-variables bias term.

Substituting equation (3) with time-varying coefficients for $(\mathrm{m}-\mathrm{p})_{\mathrm{t}}^{*}$ in equation (4) gives:

$$(m-p)_t = l_t d_{0t} + l_t d_{1t} y_t + l_t d_{2t}\left(r^t - r^m\right)_t + l_t d_{3t} r_t^m + l_t d_{4t}\Delta p_t + (1-l_t)(m-p)_{t-1}$$
$$\mathrm{t} = 1,2,3,\ldots,\mathrm{T} \qquad (5)$$

In this equation, the d's are correlated with each other and with the explanatory variables. These are the implications of the correct interpretations (given above) of d's (see Swamy and Tavlas (2001)). Equation (5) with all these correlations is the same as an equation in a simultaneous system without any exogenous variables. Therefore, it cannot be used to derive the conditional moments of its dependent variable given the values of its included explanatory variables. One question that needs to be addressed before estimating equation (5) is that of parameterisation: which features of equation (5) ought to be treated as constant parameters? Inconsistencies arise if this parameterisation is not consistent with the correct interpretations of d's. To achieve consistency, the d's are estimated using concomitants. A formal definition of concomitants is provided in Chang *et al*. (2000) and Swamy and Tavlas (2001). Intuitively, these may be viewed as variables that are not part of the explanatory variables of the money demand, but help deal with the correlations between the d's and the included explanatory variables ( $\mathrm{y}_{\mathrm{t}}, (r^t - r^m)_t,\ r_t^m,\ \Delta p_t$ ). Two additional assumptions, needed to consistently parameterise equation (5), are the following.

Assumption I. The coefficients of equation (5) are linear functions of p variables, called concomitants, including a constant term with added error terms which may be contemporaneously and serially correlated. The error terms are mean independent of the concomitants.

Assumption II. The explanatory variables of equation (5) are independent of their coefficients' error terms, and, in addition $\lambda_{\mathrm{t}}$ is independent of the coefficients of equation (3) given the values of the concomitants.

Assumption II captures the idea that the explanatory variables of equation (5) can be independent of their coefficients conditional on the given values of concomitants even though they are not unconditionally independent of their coefficients. This property provides a useful procedure for consistently estimating the bias-free effects contained in the coefficients of equation (3). Under Assumptions I and II, equation (5) can be written as

$$
\begin{aligned}
(m-p)_t &= p_{00} z_{0t} + \sum_{j=1}^{p-1} p_{0j} z_{jt} + p_{10} y_t z_{0t} + \sum_{j=1}^{p-1} p_{1j} z_{jt} y_t + p_{20} (r^t - r^m)_t z_{0t} + \sum_{j=1}^{p-1} p_{2j} z_{jt} (r^t - r^m)_t + \\
&+ p_{30} r_t^m z_{0t} + \sum_{j=1}^{p-1} p_{3j} z_{jt} r_t^m + p_{40} \Delta p_t z_{0t} + \sum_{j=1}^{p-1} p_{4j} z_{jt} \Delta p_t + p_{50} (m-p)_{t-1} z_{0t} + \sum_{j=1}^{p-1} p_{5j} z_{jt} (m-p)_{t-1} + e_{0t} + \\
&e_{1t} y_t + e_{2t} (r^t - r^m)_t + e_{3t} r_t^m + e_{4t} \Delta p_t + e_{5t} (m-p)_{t-1} \qquad (6)
\end{aligned}
$$

where the z's denote concomitants the ε's denote the error terms of the coefficients of equation (5), and the right-hand-side with the error terms suppressed gives the conditional mean of $(m-p)_t$, given the concomitants.

It might be helpful at this point to summarise the above discussion on an intuitive level, leaving more formal discussions for the interested reader (see Tavlas and Swamy (2001)). Empirical models often contain problems of omitted variables and measurement errors, introducing biases into the coefficients. It can be shown that each coefficient in any specified model is comprised of three terms: (1) a bias-free coefficient, (2) an omitted-variables-bias term, and (3) a measurement-error-bias-term. This circumstance leads to two main consequences. First, as the estimated coefficient co-mingles three terms, it would be desirable to separate the bias-free coefficient from the other two terms. Second, the structure of the three terms is such that their sum in not independent of the included explanatory variables.

To deal with these two consequences, RC estimation introduces two assumptions. Assumption I uses concomitants to explain the variations in each of the three terms of a coefficient. In particular, it splits the set of included concomitants into two subsets in such a way that one subset estimates the bias-free component and the other subset estimates the combined omitted-variables-bias term and the measurement-error-bias term. Assumption II accomplishes the independence between the explanatory variables and the remainders of coefficients obtained after removing the effects of concomitants on the coefficients (the $e's$ in equation (6)). That is, any variations in the coefficients not explained by the concomitants are assumed to be independent of the explanatory variables. In this way, the conditional expectation of the dependent variable is obtained.

In the estimation that follows, we set p=3, $z_{0t}$=1 for all t, $z_{1t}$ = the industrial production index, and $z_{2t}$= the percentage change in the deposit rate.[17] Thus, three concomitants are used to estimate the d's and $\lambda$'s. We are attempting to capture the bias-free effect contained in $d_{1t}$ by using a linear function $(\pi_{10} + \pi_{11} z_{1t})$ of the industrial production index. The omitted-variables and measurement-error bias are captured by using a function $(\pi_{12} z_{2t} + \varepsilon_{1t})$ of the percentage change of deposit rate and $\varepsilon_{1t}$. The measures of bias-free effects contained in $d_{2t}$ and $d_{3t}$ are $\pi_{20} + \pi_{21} z_{1t}$ and $\pi_{30} + \pi_{31} z_{1t}$, respectively, and those of omitted-variable and measurement-error biases contained in $d_{2t}$ and $d_{3t}$ are $\pi_{22} z_{2t} + \varepsilon_{2t}$ and $\pi_{32} z_{2t} + \varepsilon_{3t}$, respectively. The same applies for the other coefficients $\delta_{4t}$, and $d_{5t}$. We take

$$l_t = 1 - p_{50} - \underset{j=1}{\overset{p=1}{\varepsilon}} p_{5j} z_{jt} - e_{6t}\,.$$[18]

## 5. Empirical results

Table 1 presents the results of cointegration analysis among the four variables, the log of the stock of real money balances (m-p), the log of real income (y), the own rate of M3 ($r^m$) and the spread between the T-bill rate and the own rate ($r^t - r^m$). The inflation rate variable $\Delta p^e$ is included in the specification as an I(0) variable.[19] In the vector autoregressive (VAR) estimation, in addition to the slope and the two shift dummy variables, seasonal dummies were included. To determine the lag lengths of the VAR models, three versions of the system were initially estimated involving eight lags, six lags and four lags, respectively. An Akaike Information Criterion, a Schwarz Bayesian Criterion, and a likelihood ratio test (Sims test) were used to test the hypothesis that all three specifications are equivalent. Each of

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[17] The percentage change in the deposit rate and the level of industrial production were used as concomitants because of their likely correlation with the included explanatory variables. As indicated by the fact that we had to construct a quarterly series for GDP, the number of available quarterly series that could serve as concomitants was limited.

[18] Note that equation (6) has six error terms, five of which are the products of $\varepsilon$'s and the included explanatory variables of equation (5). The sum of these six terms is both heteroscedastic and serially correlated. This result shows that the addition of a single error term to a mathematical equation and the exclusion of the interaction terms on the right-hand side of equation (6) introduce inconsistencies in the usual situations where measurement errors and omitted-variable biases are present and the true functional forms are unknown. A computer program developed by Chang, *et al.* (2000) is used to estimate equation (6).

the tests suggested a lag length equal to 4. Therefore, four lags were used in the estimation procedure of cointegration. Each equation of the VAR system passed a series of diagnostic tests including tests for serial correlation based on the inspection of the autocorrelation functions of the residuals and the Lagrange multiplier test. Finally, a log-likelihood ratio test was used for testing for the exclusion of the two shift dummy variables and the seasonal dummies from the VAR model. The tests rejected the null hypothesis of the exclusion restrictions at 10 per cent (LR=8.14), 5 per cent (LR=12.82), and 1 per cent (LR=88.63), respectively.

The estimation procedure assumes unrestricted intercepts and no trends in the VAR. The two shift dummies are left unrestricted. To test for cointegration, we used the Johansen maximum likelihood approach employing both the maximum eigenvalue and trace statistics. Both test statistics rejected the null of zero cointegrating vectors in favor of one cointegrating vector at the 5 per cent level of significance. As reported in Table 2, likelihood ratio tests (described in Johansen (1992) and Johansen and Juselius (1992)) indicate that all the coefficients in the cointegrating relationship are statistically significant.

Having determined that the variables are cointegrated, VECM can be applied. The weak endogeneity of the four variables that is the log of the stock of real money balances (m-p), the log of real income (y), the own rate of M3 ($r^m$) and the spread between the T-bill rate and the own rate ($r^t - r^m$) was tested through the Error Correction Term (ECT). The size and the statistical significance of the ECT measures the extent to which the dependent variable has the tendency to return to its long-run equilibrium. The Wald-tests for the ECTs indicated that money balances and real income were not weakly exogenous (Wald statistics = 14.01 and 14.15 respectively). The own rate and the interest-rate differential were weakly exogenous (Wald statistics = 0.34 and 1.80 respectively).

In addition, the two shift dummy variables were not statistically significant in the estimated error correction models (ECM) for the own rate and the interest rate differential. The estimated t-statistics are equal to –1.83 and –0.29 for the two dummies in the own rate equation and –0.79 and 0.28 in the interest rate differential equation. These results indicate that both variables (own rate and interest rate differential) are super exogenous since there is a

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[19] All variable were tested for stationarity employing three different tests: the Augmented Dickey Fuller (ADF) test, the Phillips-Perron (PP) test and the Kwiatkowski *et al.* (KPSS) test. The results from all the tests (ADF, PP,

regime shift in the money demand equation but no significant dummies in the own rate and interest rate differential equations.

The VEC and RC results are shown in Table 3, which reports the coefficients estimated over 1976:1-1997:4 and the root mean square errors (RMSEs) for 1998:1-2000:4. For the RC specification, the coefficients are the long-run average values of the individual time-varying coefficients and the corresponding t-ratios. Three sets of RC results are reported: (1) RC1 applies RC estimation to equation (6) without concomitants (other than the constant term); (2) RC2 applies RC estimation to equation (6) with a single (other than the constant term) concomitant (the annual percentage change in the deposit rate); and (3) RC3 applies RC estimation to equation (6) with two (other than the constant term) concomitants (the annual percentage change in the deposit rate and the level of industrial production).

As shown in Table 3, both the RC and VEC models produce estimates of the elasticities of income and the opportunity cost variables that are within the range of estimates yielded in previous empirical studies of money demand (e.g., see Laidler (1993)). The VEC specification gives a long-run income elasticity of 1.67, which is close to the implied long-run elasticity of 1.62 given by RC1; note, however, that the addition of concomitants results in a progressively lower (implied) long-run income elasticity in the RC models. The use of a broad monetary aggregate may have contributed to higher income elasticities than those found in other recent papers on Greek money demand.[20] The semi-elasticity of the opportunity cost variable is greater in absolute value under VEC than under the RC specification, though this finding could reflect the inclusion of the expected inflation rate as a separate variable under RC. The own rate semi-elasticity is also higher under VEC than under RC.

As noted, the post-sample forecast period is 1998:1 – 2000:4. This period provides a good test of forecasting ability. A regime change occurred in March 1998 when the drachma was devalued and joined the ERM (see Section 2.3). In September 1998, a 15 percent withholding tax on repos, which are included in M3, was lifted. As a result, a portfolio shift into repos occurred and M3 growth shot up from an annual rate of 4.4 percent in 1998, to 22.0 percent in 1999 and 16.7 percent in 2000. Also, in 1999 the Bank of Greece discontinued the

KPSS) suggest that all the series except the inflation rate are I (1) processes while the inflation rate is an I (0) process.

[20] Previous studies of Greek money demand, using narrower aggregates, report the following elasticities. Papadopoulos and Zis (1997) obtain elasticities of 1.49 for M.1 and 2.04 for M2. Karfakis (1991) and Psaradakis (1993), both using M1, obtain elasticities of 1.15 and 1.45 respectively.

practice of using M3 as an intermediate target variable. As shown in Table 3, RC1 produces a RMSE of 5.1 per cent. Adding concomitants in the RC specification successively reduces RMSEs, to 4.5 per cent under RC2 and to 4.1 percent under RC3. The RMSE for VEC is 11.8 per cent.

As pointed out in the last paragraph of Section 4.2, the use of two concomitants in RC3 permits a separation of the bias-free effects components from the coefficients, which are called "total" effects because they include omitted-variable and measurement-error biases. These effects are reported in Table 4. The differences between the average total and bias-free effects are small. Therefore, based on the two assumptions (Assumption I and II) used to derive equation (6) from equation (5), measurement-error and omitted-variable biases would not appear, on average, to have had a significant effect on the RC biased effect estimates.

To examine how the behaviour of the RC coefficients corresponds to *a priori* considerations, the time-varying behavior of the coefficients, based on RC3 estimation, was used to trace the time profile of the coefficients (both bias-free and biased effects). These results are reported in Figures 2 through 5. (These Figures also show the time profiles of the coefficient estimates obtained from VEC recursive estimation). Several points merit comment. First, although the bias-free and biased effects contained in two of the four coefficients tend to move together, the bias-free effect contained in all of the four coefficients displays much less volatility over time than the biased effect, indicating that the impact of specification errors on the time profile (as opposed to the average values of the coefficients) have been of some importance. Second, the long-run income elasticity fluctuated around a declining trend throughout 1976:1-1989:4; it then fluctuated around an increasing trend before it again started fluctuating around a declining trend in 1993:3-1997:4 (Figure 2). It was about 1.7 in the late 1970s, but fell to about 1.2 at the end of the estimation period. This result is consistent with the hypothesis, discussed in Section 2, that the income elasticity of real money balances is inversely related to the degree of development of the financial system. Also, the result is consistent with findings (noted in Section 2) of previous empirical studies that the income elasticity has a tendency to approach unity. As noted in Section 2, however, the declining income elasticity could also be capturing a rise in the wealth-to-income ratio, which could not be used because of data limitations. Third, the time profiles of the own-rate and opportunity cost coefficients are each consistent with the hypothesis that the demand for money has become more responsive to both the own-rate and the rates on money substitutes because of financial deregulation and financial development. As shown in Figure 3, the own rate coefficient rises from about .01 at the beginning of the estimation period to about .03 at the end of the period. As shown in Figure 4, the (negative) coefficient on the T-bill rate-own rate differential rises in absolute value from around .01 to about .04. The (negative) coefficient on the expected inflation rate rises in absolute value from about .01 to around .02.

The VEC model was re-estimated recursively; the time profiles of the coefficients are also displayed in Figures 2 through 4.[21] As shown in Figure 2, the income elasticity of the VEC fell from about 1.7 in 1982 to around 1.4 in 1993; by 1993 the VEC estimate converged to that provided by RCE. In 1994:1, the VEC elasticity displays an upward shift, rising to about 1.7, where it remains for the remainder of the period.

Regarding the VEC own rate and T-bill differential elasticities, as reported in Figures 3 and 4, respectively, the time profiles show that the semi-elasticities increase in absolute value during the course of the estimation period, which is consistent with the RCE results. The absolute values of the recursive VEC estimates are somewhat higher than the comparable RC estimates; this result may be due to the use of the expected inflation rate as an additional proxy for the opportunity cost of holding money in the RC specification. The use of this proxy may have resulted in lower semi-elasticities of the own rate and the interest-rate differential in the RC specification. It is also worth pointing out that the time profile of the interest rate differential term produced by recursive VEC estimation closely follows that of the biased effect produced by RCE (Figure 4). As noted above, the biased effect of (or the coefficient on) the interest-rate differential in equation (5) is not purged of omitted-variable and measurement-error biases.

The differing behavioural patterns of the RC and VEC recursive estimates of the income coefficient, beginning in 1994, warrant further comment. The higher elasticity given by recursive VEC estimation is to be expected. Recall, a dummy variable was used beginning in 1994:1 to pick up the effect of sales of government bonds to the public. Inclusion of the dummy appears to affect the coefficient on income, allowing it to shift back upward so that, in effect, a stable, long-run coefficient is obtained over the entire period. By changing the income elasticity, the shift dummy produces cointegration.

Recursive VEC estimation is a way of testing for stability. If the structure is changing, however, recursive VEC estimation does not give consistent estimates of the changing parameters. Unlike RC estimation, an underlying assumption of recursive estimation in that the coefficients are constant. Also, recursive estimation does not write off the past. If a regime change has occurred, it averages the old regime with the new regime with changing weights; the weight of the new regime becomes larger as more and more observations are added. Using recursive estimation, the best estimate of a model is that produced by the entire sample. RCE, in contrast, picks up a new regime quickly. By consistently estimating changing coefficients, it attempts to estimate how the true coefficient is changing at each point in time.

As discussed, recursive estimation is relevant for testing the hypothesis of stability. Accordingly, the stability of the long-run relationship was tested using recursive VEC estimation of the one-step Chow test, break point Chow test, and forecast Chow test. The results indicate some instability at the 5 per cent level of significance in the estimated relationship in the mid-1990s. Cointegration, however, requires stable long-run parameters. While the coefficients fluctuated in the short run, the shift dummy allowed the estimated coefficients to return to their long-run values, thereby providing cointegration. The Chow procedure tests for stability in the short run in each period. Therefore, we can conclude that there is instability in some periods in the short run.[22]

## 6. Conclusions

This paper has estimated the demand for money in Greece over a period involving considerable structural change. The results of VEC and RC estimation show that money demand became more responsive to both the own rate of return on money balances and the opportunity cost of holding money because of financial deregulation. In general, both procedures also support the hypothesis that the income elasticity of money demand declines over time as a result of technological improvements in the payments system and the development of money substitutes, which lead to economies of scale in holding money.

For most of the period under consideration in this paper, monetary growth was one input into the policy decisions of the Bank of Greece. Although the coefficients of the money demand function appear to have changed, they did so in a way that was consistent with *a priori* considerations. Thus, keeping a watchful eye on the monetary aggregates provided a

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[21] To perform recursive estimation, 27 observations were lost due to initialisation.
[22] The results for the Chow test are obtained using PcFiml 9.0 (see Doornik and Hendry (1997)). The recursive Chow-test statistics are available from the authors upon request.

useful source of information to the monetary authorities. Yet, monetary targets never obtained overriding importance in Greece. The changing character of the demand for money indicates that the decision to monitor the aggregates, but not to strictly target money growth, was well-placed.

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**Table 1**

Johansen and Juselius Cointegration Tests

Long-run Demand for Money in Greece: Sample 1976:1-1997:4

VAR=4, Variables: (m-p), y, $r^t - r^m$, $r^m$

($\Delta$p) is included as I(0) variable in the VAR

*Maximum Eigenvalues*

| Null | Alternative | Eigenvalue | Critical Values 95% | Critical Values 90% |
|---|---|---|---|---|
| r=0 | r=1 | 36.88** | 27.42 | 24.99 |
| r<=1 | r=2 | 15.75 | 21.12 | 19.02 |
| r<=2 | r=3 | 10.63 | 14.88 | 12.98 |
| r<=3 | r=4 | 1.63 | 8.07 | 6.50 |

*Trace Statistic*

| Null | Alternative | Trace | Critical Values 95% | Critical Values 90% |
|---|---|---|---|---|
| r=0 | r>=1 | 64.89** | 48.88 | 45.70 |
| r<=1 | r>=2 | 28.00 | 31.54 | 28.78 |
| r<=2 | r>=3 | 12.26 | 17.86 | 15.75 |
| r<=3 | r>=4 | 1.63 | 8.07 | 6.50 |

$$Z = m\text{-}p\text{-}1.67y+0.038(r^t - r^m)\text{-}0.05\, r^m$$

*Note*: r indicates the number of cointegrating relationships. Maximum eigenvalue and trace test statistics are compared with the critical values from Johansen and Juselius (1990). ** indicates rejection of the null hypothesis at 95 percent critical value, respectively.

**Table 2**

Long-Run Hypothesis Testing

| Variables | LR Test of Restrictions that each variable does not enter in the cointegrating vector |
|---|---|
| m-p | 20.99*** |
| y | 14.02*** |
| $r^t - r^m$ | 3.74** |
| $r^m$ | 21.10*** |

Notes: The reported statistics are distributed as chi-square distribution with degrees of freedom the number of cointegrating vectors for the first test and the number of restrictions for the second test. *** and ** indicate rejection of the null hypothesis at 1 and 5 percent level of significance.

**Table 3: Results from VEC and RC Methodologies**

| | Coefficients on | | | | | |
|---|---|---|---|---|---|---|
| Model | Constant | Real income (y) | Spread between $t^b$ and own rate $(r^t - r^m)$ | Own rate $(r^m)$ | Inflation $(\Delta p)$ | RMSE |
| VEC | | 1.674 | -0.038 | 0.053 | | 0.118 |
| | | (0.29) | (0.018) | (0.005) | | |
| | -7.83 | 1.619 | -0.035 | 0.035 | -0.018 | 0.051 |
| RC1 | (-9.5) | (15.3) | (-2.4) | (5.4) | (-3.7) | |
| | -6.14 | 1.417 | -0.010 | 0.015 | -0.010 | 0.045 |
| RC2 | (-6.6) | (4.6) | (-1.1) | (2.6) | (-1.0) | |
| | -5.60 | 1.327 | -0.009 | 0.027 | -0.014 | 0.041 |
| RC3 | (-6.7) | (17.0) | (-0.9) | (3.4) | (-1.3) | |

Notes: The estimation period for all the models is 1976:1 to 1997:4 and the forecast period is 1998:1 to 2000:4. The figures in parentheses for the VEC results are the standard errors. These standards erros do not follow the t-distribution. The coefficients for the RC models are averages over the estimation period. Figures in parentheses for the RC results are t-ratios. The RC coefficients are the long-run values.

**Table 4**
**Post-Sample Forecasts (RMSEs) 1/**

| Model | 1989-1991 | 1992-1994 | 1995-1997 |
|---|---|---|---|
| VEC | 0.082 | 1.223 | 0.028 |
| RC3 | 0.043 | 0.035 | 0.080 |

1/ Forecasts are based on equations estimated over the 52 observations prior to the forecast interval. For example, forecasts for the 1989-1991 are based on estimates made over the period 1976:1-1988:4.

**Table 5: RC Estimates of Direct and Total Effects 1/**

| Model | y | | $r^t$-$r^m$ | | $r^m$ | | $(\Delta p)$ | |
|---|---|---|---|---|---|---|---|---|
| | Total Effect | Direct Effect | Total Effect | Direct Effect | Total Effect | Direct Effect | Total Effect | Direct Effect |
| RC3 | 1.327 | 1.324 | -0.010 | -0.009 | 0.0273 | 0.0274 | -0.014 | -0.018 |
| | (17.0) | (16.9) | (-0.9) | (-1.0) | (3.4) | (3.4) | (-1.3) | (-1.9) |

1/ Numbers in parentheses are t-ratios.

**Figure 1b. General Government Deficit, 1975-2000 (Percent of GDP)**

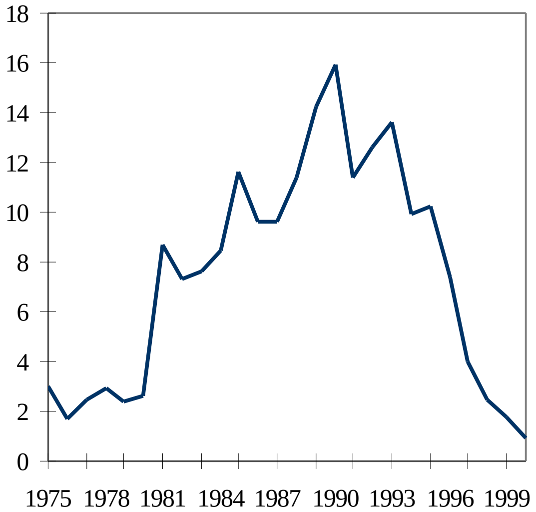



**Figure 1a. Greece and Industrial Countries: Inflation, 1975-2000 (Annual percentage changes in CPI)**

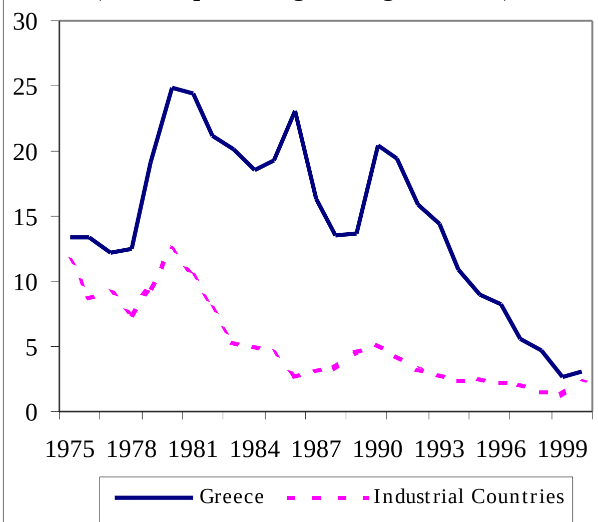



**Figure 1c. M3, 1976-2000 (Annual percentage changes)**

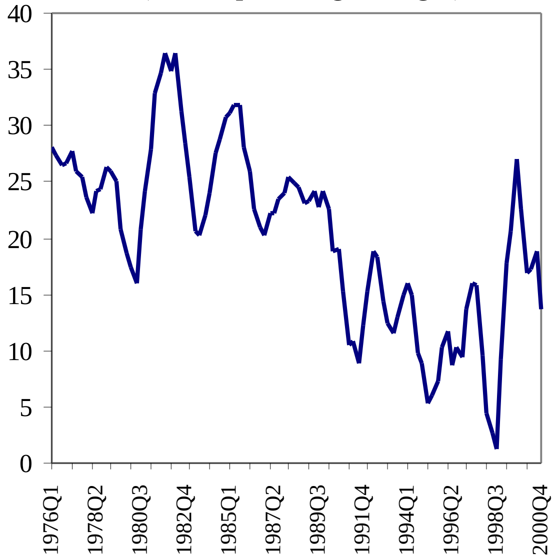
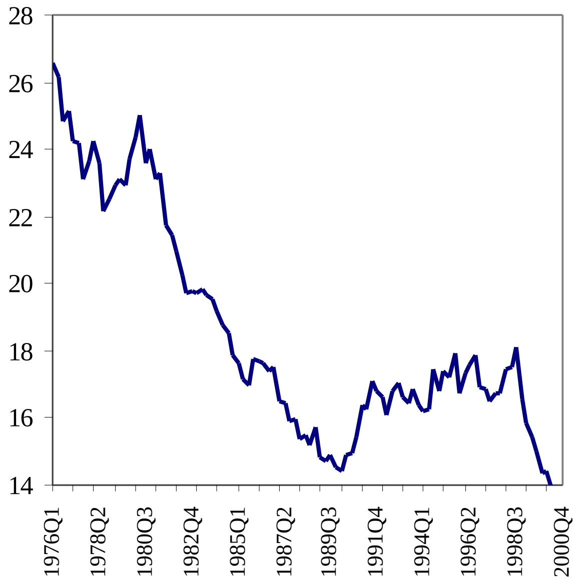



**Figure 1d. Velocity of M3, 1976-2000**



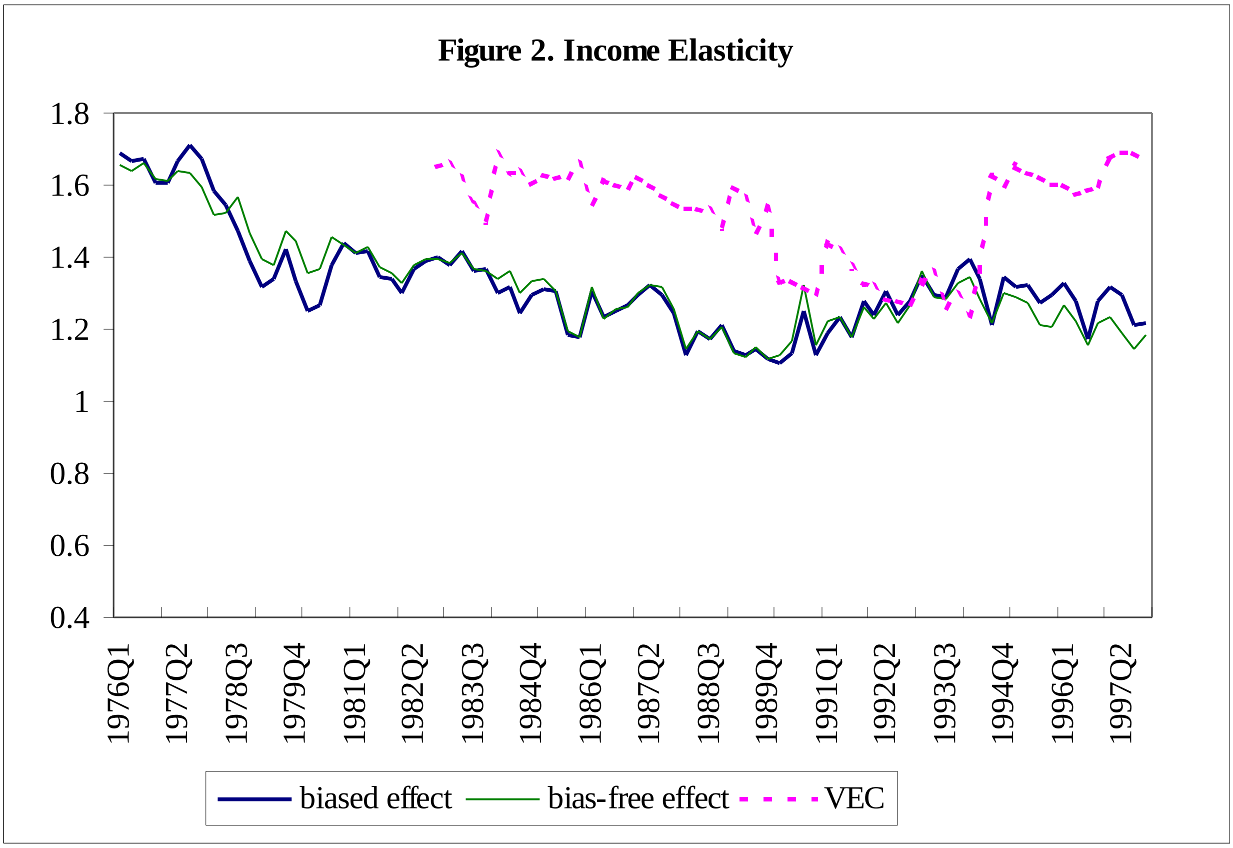


Figure 2. Income Elasticity
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
1976Q1
1977Q2
1978Q3
1979Q4
1981Q1
1982Q2
1983Q3
1984Q4
1986Q1
1987Q2
1988Q3
1989Q4
1991Q1
1992Q2
1993Q3
1994Q4
1996Q1
1997Q2
biased effect
bias-free effect
VEC

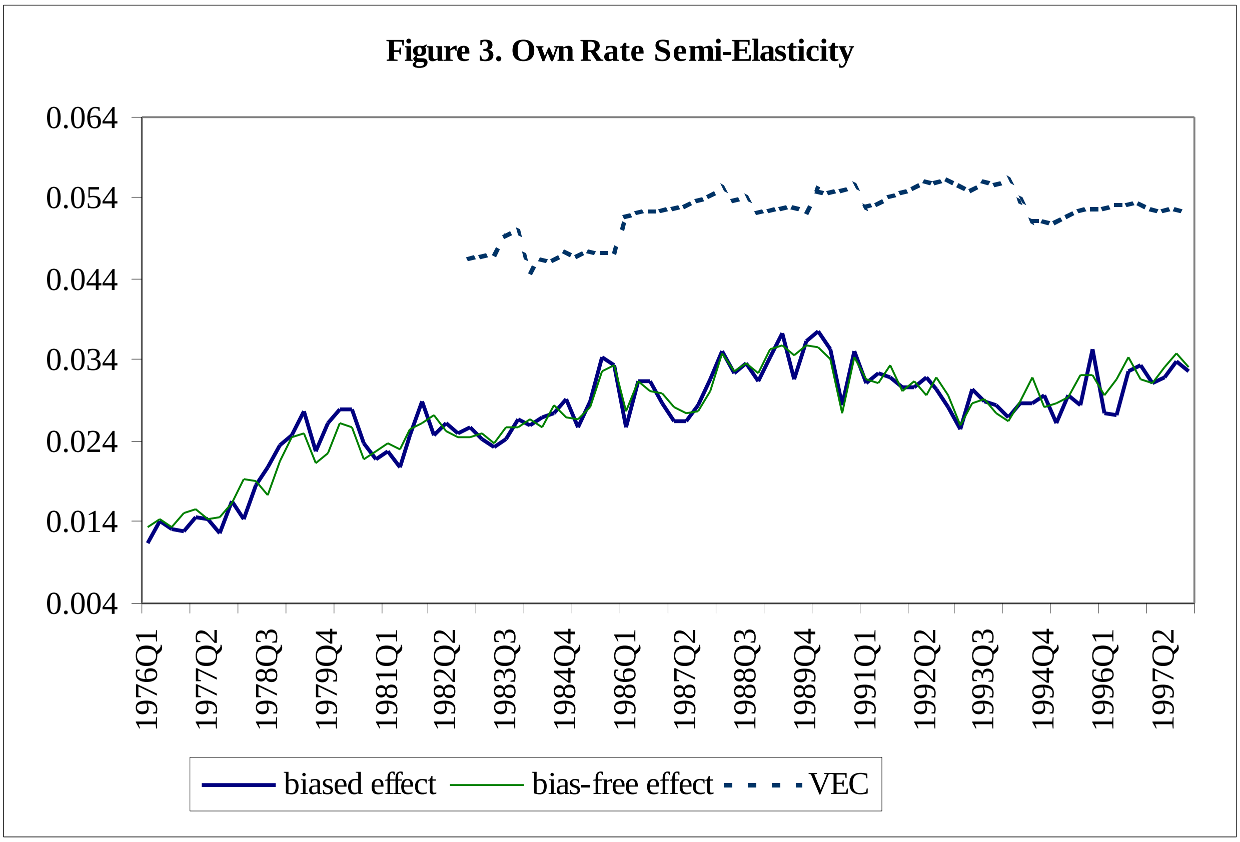


Figure 3. Own Rate Semi-Elasticity
0.064
0.054
0.044
0.034
0.024
0.014
0.004
1976Q1
1977Q2
1978Q3
1979Q4
1981Q1
1982Q2
1983Q3
1984Q4
1986Q1
1987Q2
1988Q3
1989Q4
1991Q1
1992Q2
1993Q3
1994Q4
1996Q1
1997Q2
biased effect
bias-free effect
VEC

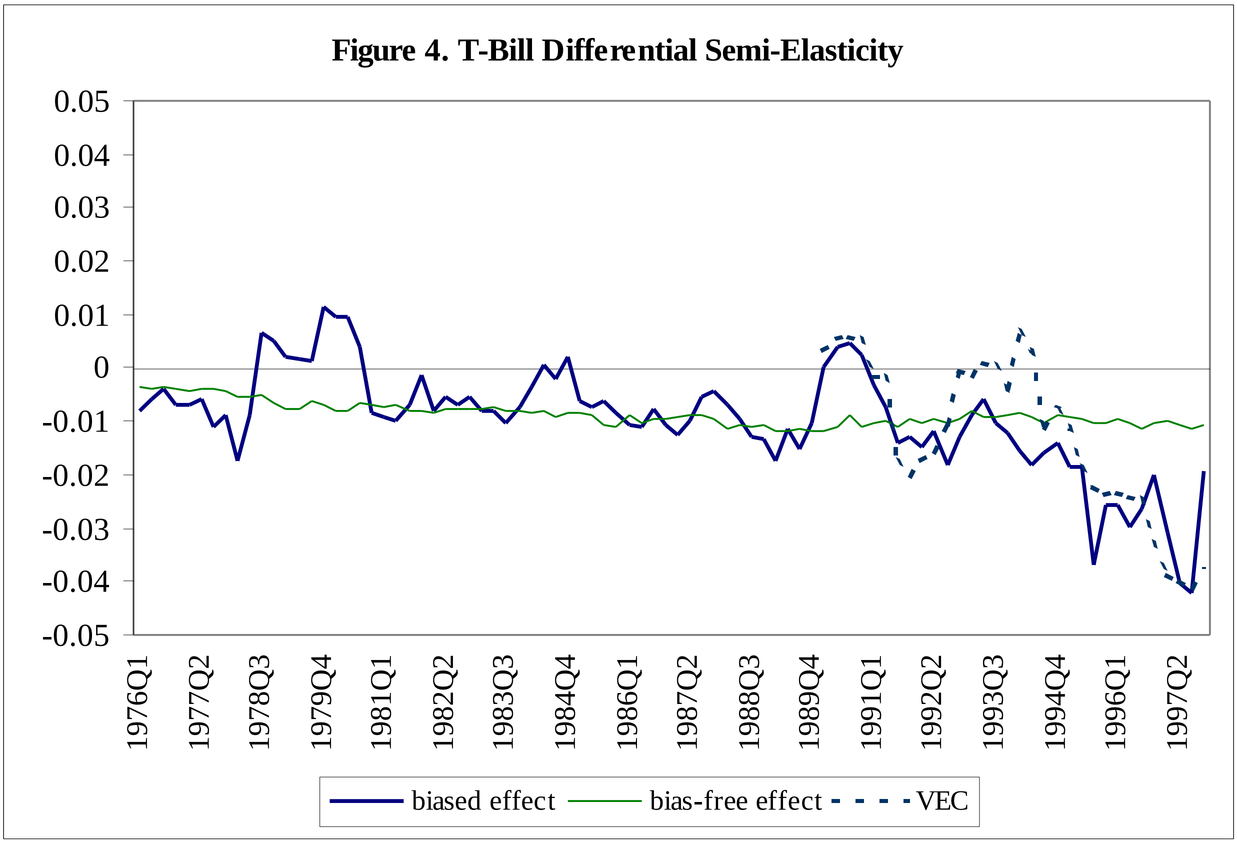


Figure 4. T-Bill Differential Semi-Elasticity
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
1976Q1
1977Q2
1978Q3
1979Q4
1981Q1
1982Q2
1983Q3
1984Q4
1986Q1
1987Q2
1988Q3
1989Q4
1991Q1
1992Q2
1993Q3
1994Q4
1996Q1
1997Q2
biased effect
bias-free effect
VEC

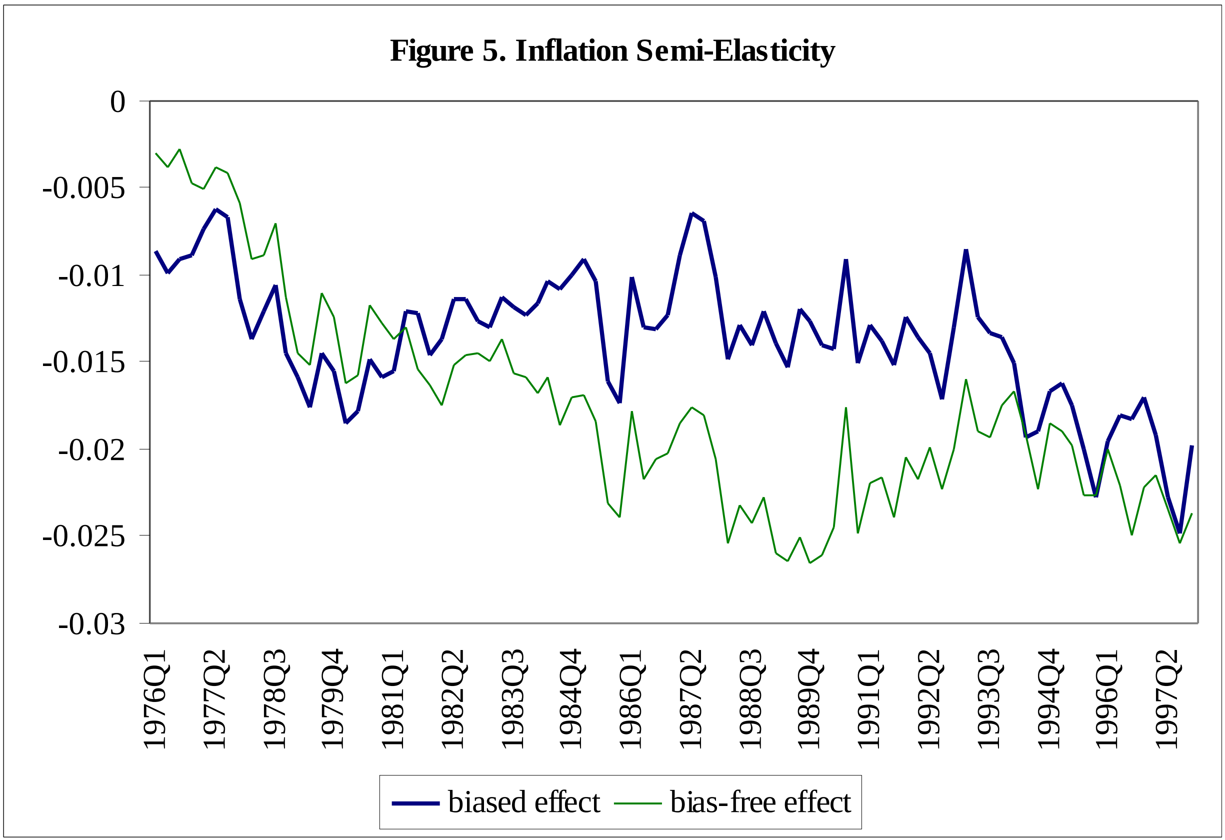


Figure 5. Inflation Semi-Elasticity
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
1976Q1
1977Q2
1978Q3
1979Q4
1981Q1
1982Q2
1983Q3
1984Q4
1986Q1
1987Q2
1988Q3
1989Q4
1991Q1
1992Q2
1993Q3
1994Q4
1996Q1
1997Q2
biased effect
bias-free effect