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Revisiting the demand for money function: evidence from the random coefficients approach

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This article employs second-generation random coefficient (RC) modeling to investigate the time-varying behavior and the predictability of the money demand function in Taiwan over the period from 1982Q1 to 2006Q4. The RC procedure deals with some of the limitations of previous studies, such as unknown functional forms, omitted variables, measurement errors, additive error terms, and the correlations between explanatory variables and their coefficients. Our main findings are as follows. First, the empirical results indicate that the values of the elasticities in the RC estimation are significantly different from those in other studies, because of the use of coefficient drivers. Second, by observing the time-varying behavior of the coefficients, we find some specific points in our time profile of coefficients; that is, we can make an association with real events occurring in Taiwan, such as the financial liberalization after 1989 and the Asian financial crisis of 1997–1998. Finally, we compare the predicted values via the time intervals and different specifications and find that we should adapt different specifications of the RC model to estimate each interval.

Keywords: Money demand; Random coefficient estimation; Time-varying; Predictability

JEL Classification: C2, C22, E4, E41, E47

1. Introduction

The relationship between money and economic activities is an issue of great concern to policy-makers owing to the impact of monetary policy on a country's economy. The money demand function is important in both macroeconomic and financial analysis, especially in selecting appropriate monetary policy performances (Narayan *et al*. 2009). Different specifications of the demand for money, as revealed in various empirical outcomes, result in divergent measures and specifications of models, thereby bringing the issue of what constitutes an accurate model of the demand for money into dispute. Moreover, the economic and financial environments encounter a variety of influences that often cause money-demand instability (Brissimis *et al*. 2003, Lee 2011). Since it is reasonable to suspect that money demand might have become unstable due to a number of financial or economic liberalization measures from the 1980s, interest in developing countries has heightened in recent years, including Sriram (2002) for Malaysia, Pradhan and Subramanian (2003) for India, Bahmani-Oskooee and Rehman (2005) for six Asian developing countries, Akhtaruzzaman (2007) for Bangladesh, Lee and Chien (2008) for China, Darrat and Al-Sowaidi (2009) for three emerging market economies in the Gulf region, Rao and Kumar (2009) for 14 Asian countries, and Sumner (2009) for Thailand.§

Specifically, developing countries are significantly different with respect to their degrees of economic openness and liberalization, macroeconomic and financial environments, and the cause of new challenges in modeling the money demand function. Certainly, a limited number of studies have attempted to identify the key macroeconomic variables that determine the demand for money in Taiwan; however, only a few studies have investigated

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§Kia (2006) demonstrates that it is possible for a policy regime change to affect the parameters of the relevant model. These estimated parameters are not constant if their changes are unpredictable or conflict with what the policy-makers had predicted.

the stability and the predictability of the money demand function.† In particular, over the past 50 years, Taiwan has given rise to a miracle of economic development in which a successful monetary policy has played an important role. Furthermore, studies in Taiwan were completed in the 1980s and 1990s, and therefore could not accommodate the impact of globalization and financial liberalization on money demand. Our study considers evidence for the most recent period. More importantly, an innovation of this study is the choice—based on an extensive study—of a random coefficient model to identify the causes of coefficient instability using a set of 'driving' variables that explain the time variation in the coefficients.

This paper is novel for five reasons. First, by using quarterly data from 1982Q1 to 2006Q4,‡ we specify a new framework for money demand in Taiwan that is similar to the second-generation random coefficient (RC hereafter) model.§ This framework is implemented to investigate the behavior that, according to the measures obtained for the coefficients, varies across time.¶ Based on this approach, we further observe each time point and contrast it with actual events that have occurred during the period in question. Second, other nonlinear approaches relative to the second-generation RC approach may take the form of omitted variables, endogeneity problems, measurement errors, and incorrect functional form. The coefficient drivers are used to deal with the correlation between the included explanatory variables and their coefficients, as well as allowing us to decompose the coefficients of the RC model into their respective components (Hall *et al.* 2009). Third, in order to obtain robust evidence, we examine six specifications proposed in our RC model. Fourth, because this framework is the first of its kind to employ the RC model to evaluate the demand for money in Taiwan, we might compare the estimates of the elasticities that it yields with the findings of other studies conducted in Taiwan. Specifically, we investigate the stability of the demand for money as predicted by the time-varying coefficients, thus helping to demonstrate the evolution of the demand for money given the structural changes in Taiwan's economy. Fifth and finally, we use root mean square errors (RMSEs) to investigate the performance of each equation predicted by our RC estimation procedure.

From a policy point of view, this research is original in that it is the first study that models money demand in Taiwan within a second-generation RC framework. Having accurate information on the elasticities is important for projecting the related financial or economic policies in the future (Lee and Chiu 2012). This paper investigates the demand for money in Taiwan and traces the time-varying profiles of the coefficients. The Taiwan context provides a considerable challenge for empirical models of money demand, because it is a newly industrializing country with a rapidly changing financial market, the implementation of many measures to deregulate its financial markets, and the encouragement of innovation over the last two decades. Since 1980, the central bank has focused on 'adjusting interest rates', and several steps to facilitate financial liberalization have been introduced. For example, many new stock exchange companies and private banks have entered the market, interest rates have been deregulated, and outside investors have entered the foreign exchange market. Against such a background, the checkered economic system provides us with an opportunity to consider the stability of the demand for money. Moreover, financial reforms have increased competition, created new money substitutes, expanded electronic money transfers and led to greater international capital mobility (Rao and Kumar 2009).

Shen (1998) considers the demand for money function in Taiwan to be unstable. There are other studies on the demand for money in Taiwan, for example Chang (1989), Cheng and Hu (1997), and Lin (1997). These works indicate that the relationship between variables and money is insignificant, and that the estimation models are specified in advance while the true forms are not known. Therefore, discussion of the RC model's specification is not without contention.⊥ Moreover, if one neglects the possibility that the money demand function could be nonlinear, then the results obtained using traditional linear time series specifications might cause bias, due to the usage of a false estimation method (Haug and Tam 2007, Hall *et al.* 2009, Hondroyiannis *et al.* 2009). Calza and Zaghini (2009) further show that the nonlinearities for money demand are typically rationalized on the basis of target-threshold and theoretical buffer stock models.

The stability of the demand for money function is currently the central proposition in monetary economics. Such demand plays a key role in many economic models such as those encompassing the New Keynesian analysis and the new Classical approach, as well as in real business cycle models.‖ In addition, there are many empirical studies that have examined the demand for money

†Payne (2003) indicates that the relative absence of empirical money demand studies for developing economies is partly due to the relative instability of these economies in the transition process itself, as well as the concerns over the reliability and frequency of time series data.

‡Where Q1 is the quarter ending in March, and Q4 is the quarter ending in December.

§Swamy and Tavlas (1995, 2001) and Hondroyiannis *et al.* (2008) distinguish between first- and second-generation random coefficient models. First-generation RC regressions are, however, not free of misspecifications, because they do not take into account the correlations between the included explanatory variables and their coefficients.

¶Similar to a general regression approach, time-varying coefficients allow us to truly reflect the estimated periods. However, general regression coefficients provide us with long-term time trends at the expense of being able to easily analyse individual points.

⊥The reason why we do not consider the unit root and cointegration is that we want to observe the time-varying behaviors of the coefficients and the performance of prediction. This is different from previous papers that focus on the treatment of data.

‖Studies that highlight these arguments include Sargent and Wallace (1975), Mankiw (1992), and King *et al.* (1991).

function, although with varying results. While Hendry and Ericsson (1991) and Hoffman *et al.* (1995) consider the demand for money function to be stable,† Baharumshah *et al.* (2009) indicate stock prices are important for the stability of M2 in China. However, Goldfeld (1973) and Narayan (2007) argue that the demand for money function is unstable. Bahmani-Oskooee and Rehman (2005) report that, in some Asian countries, even though real M1 or M2 monetary aggregates are co-integrated with their determinants, the estimated parameters are unstable according to the CUSUM and CUSUMSQ tests carried out. Chen and Wu (2005) indicate that the empirical evidence on the issue of stable money demand is mixed. Carstensen *et al.* (2009) identify stable money demand relationships for Spain, France, and Germany as well as the EMU-4 aggregate. For Italy, the money demand function does not appear to be very stable over a larger part of the sample. Narayan *et al.* (2009) investigate the stability of the money demand function and reveal somewhat mixed results, in that, except for Nepal, they find some evidence of stable money demand functions for other south Asian countries.

Subsequent papers argue that the demand for money with their determinants may not follow a linear process, for instance Teräsvirta and Eliasson (2001) for the US, Huang *et al.* (2001) and Wu and Hu (2007) for Taiwan, Chen and Wu (2005) for the US and the UK, Haug (2006) for Canada, Maki and Kitasaka (2006) for Japan, and Fukuda (2008) for Canada, UK, and Japan, and Dreger and Wolters (2010) and Calza and Zaghini (2009) for the Euro area.

There are a great many studies that involve analysis using the RC models, such as Ullah and Raj (1980) who use a polynomial lag model with a stochastic coefficient. Brissimis *et al.* (2003) take a RC model and a cointegration model to examine the demand for money function in Greece. Swamy and Tinsley (1980) construct a model framework using exogenous variables as determinants that include RC models. However, Swamy and Tavlas (1995) focus on both the theory and application of RC models. Hondroyiannis *et al.* (2001a) find the long-run demand for money using annual data from 1889 to 1995 for the UK, based on a RC model with time-varying behavior. Brissimis *et al.* (2003) apply an RC estimation to show that money demand becomes more responsive to both the own-rate of return on money balances and the opportunity cost of holding money due to financial deregulation in Greece. Hall *et al.* (2009) apply the RC approach to demonstrate that money is acting as an exogenous process determining the price level.

The RC model attempts to deal with some of the restrictions that characterize the traditional model, including the shortcoming of the traditional model of having a single error term in the expression used to find the stochastic economic phenomena. Second, even though the functional form is established, the true form is still uncertain. Furthermore, the possible correction is not significant between the excluded and included variables. Finally, the errors involved in calculating the variables are not significant. The RC method can release some parts of the functional forms that are abridged.

This paper applies the specification of Friedman and Schwartz (1982), who use the nominal interest rate, real income per capita, and nominal income growth as independent variables. The use of real M2 (broad money) as the dependent variable is based on various opinions.‡ Shen (1998), on the one hand, argues that the relationship between M1B and GDP is lost, because Taiwan experiences financial innovation in the same way as the US does. Furthermore, the own-rate is used in our specification as a coefficient driver, because of its importance stressed by Ericsson (1998), who considers that the own-rate should be taken into account when financial innovation takes place.

The remainder of this study is structured as follows. Section 2 introduces the methodology and the empirical model. Section 3 provides the data description and empirical results. Section 4 concludes.

2. Methodology and empirical model

Our empirical model uses the RC estimation procedure as a framework, with the Kalman filter of the state space model subsequently being used to observe the fixed and recursive coefficients. The parameters are then calculated using the logarithmic likelihood function by means of maximum likelihood estimation. The original functional form of the money demand model is specified by Friedman and Schwartz (1982) and Hondroyiannis *et al.* (2001a,b):

$$\ln(m_t) = \beta_0 + \beta_1 \ln(r_t) + \beta_2 \ln(y_t) + \beta_3 \ln(g_{yt}) + \varepsilon_t, \quad (1)$$

where m_t is the stock of real money balances at time t, y_t is real income, r_t is the nominal interest rate, g_{yt} is the growth of nominal income, and the estimated β_i are the coefficients with subscript i ($i = 0, 1, 2, 3$). The application of a standard estimation procedure has some limitations that include the following: (i) the coefficients (β) are time invariant; (ii) excluded explanatory factors are represented by the error terms, which are assumed to have means equal to zero and are independent of the other variables in the equation; (iii) linearity or nonlinearity is not taken into consideration; and (iv) the included variables are not contingent upon their errors.

†Schmidt (2007) finds that the rolling regression results highlight significant stability within the M1 demand vector and its long- and short-run parameters.

‡M2 is generalized currency in Taiwan. It includes M1B, time deposits, and postal savings re-deposits. However, M1B includes M1A (net currency, checking deposits, and current accounts) as well as savings deposits. Over time, broad money accommodates new instruments created as a result of the ensuing development of institutional and financial structures.

In order to avoid these restrictions, we use the RC estimation to re-specify the original specification.† We thus assume that each explanatory variable has the error terms

$$\ln(m_t) = \ln(m_t^*) + \omega_{0t},$$
$$\ln(r_t) = \ln(r_t^*) + \omega_{1t},$$
$$\ln(y_t) = \ln(y_t^*) + \omega_{2t},$$
$$\ln(g_{yt}) = \ln(g_{yt}^*) + \omega_{3t},$$

where the variables with an asterisk represent the true values, and ω_{it} $(i = 0, 1, 2, 3)$ represent the error in the estimation of the variables. We specify the determinants of the random variables incorporated into ω as follows:

$$\ln(m_t^*) = \beta_{0t} + \beta_{1t}\ln(r_t^*) + \beta_{2t}\ln(y_t^*) + \beta_{3t}\ln(g_{yt}^*) + \sum_{j=4}^{n_t}\beta_{jt}\theta_{jt}^*, \quad (2)$$

where θ_{jt}^* are the determinants of each true value variable, and the true value is unknown. Term β_{it} refers to the time-varying coefficients which are denoted by the time subscripts and the direct effect on each variable.‡ However, an obvious problem in the process is that θ_{jt}^* cannot be identified. Therefore, it cannot be proved that any unidentified variable is not correlated with any other explanatory variable. The way that we solve this problem is by using the following specification:

$$\theta_{jt}^* = \phi_{0jt} + \phi_{1jt}\ln(r_t^*) + \phi_{2jt}\ln(y_t^*) + \phi_{3jt}\ln(g_{yt}^*), \quad \text{for } j = 4, \ldots, n_t. \quad (3)$$

We then substitute equation (3) for equation (2) and rewrite it slightly to obtain

$$\ln(m_t) = \gamma_{0t} + \gamma_{1t}\ln(r_t) + \gamma_{2t}\ln(y_t) + \gamma_{3t}\ln(g_{yt}), \quad (4)$$

where

$$\gamma_{0t} = \beta_{0t} + \sum_{j=4}^{n_t}\beta_{jt}\phi_{0jt} + \omega_{0t},$$
$$\gamma_{1t} = \left(\beta_{1t} + \sum_{j=4}^{n_t}\beta_{jt}\phi_{1jt}\right)[1 - (\omega_{1t}/\ln(r_t))],$$
$$\gamma_{2t} = \left(\beta_{2t} + \sum_{j=4}^{n_t}\beta_{jt}\phi_{2jt}\right)[1 - (\omega_{2t}/\ln(y_t))],$$
$$\gamma_{3t} = \left(\beta_{3t} + \sum_{j=4}^{n_t}\beta_{jt}\phi_{3jt}\right)[1 - (\omega_{3t}/\ln(g_{yt}))].$$

Since the RC model permits equation (4) to pass through every data point, thus with RC estimation the equation can be nonlinear. To emphasize the significance of the coefficients, there are three types of effects on the variables. If we take the interest rate as an example, then first of all β_{1t} represents the direct effect of the interest rate.§ Second, the term $(\sum_{j=4}^{n_t}\beta_{jt}\phi_{1jt})$ represents the omitted variable bias, and $-(\beta_{1t} + \sum_{j=4}^{n_t}\beta_{jt}\phi_{1jt}) \times [\omega_{1t}/\ln(r_t)]$ is the measurement error.

In order to deal with the direct effects in which the measurement errors and omitted-variable bias are included, we use instrumental variable estimation. Recall that equation (4) consists of three components. One of these components measures the direct effects, therefore we will use coefficient drivers to estimate the coefficients.¶ This specification can be implemented more precisely by reforming the stochastic law of the coefficients in equation (4) as follows:

$$\gamma_{\eta t} = \pi_{\eta 0} + \sum_{j=1}^{b-1}\pi_{\eta j}e_{jt} + \varepsilon_{\eta t}, \quad \text{for } \eta = 0, 1, 2, 3, \quad (5)$$

where e_{jt} are the coefficient drivers, which explain the variation in $\gamma_{\eta t}$.⊥ Here, $\varepsilon_{\eta t}$ are the stochastic equations that satisfy the AR(1) process

$$\varepsilon_{\eta t} = \alpha_{\eta\eta'} \cdot \varepsilon_{\eta,t-1} + \delta_{\eta t}, \quad (6)$$

where $-1 < \alpha_{\eta\eta'} < 1$ and $\delta_{\eta t}$ are satisfied, and $E(\delta_{\eta t}) = 0$ and $E(\delta_{\eta t}\delta_{\eta' t}) = \sigma_{\eta\eta'}$ for all t.

For the specification of the coefficient drivers, we continue using the setting of Hondroyiannis *et al.* (2001a) with four coefficient drivers. They are: e_{1t}, the own-rate; e_{2t}, the interest rate (long term or short term) or the growth of nominal income; e_{3t}, the inflation rate; and e_{4t}, the unemployment rate. The details are as follows.

(1) RC1: We use the short-term interest rate, real income, and the growth of nominal per capita income as the explanatory variables. No coefficient drivers are included.
(2) RC2: We use the long-term interest rate, real income, and the growth of nominal per capita income as the explanatory variables. No coefficient drivers are included.
(3) RC3: We use the long-term interest rate, the short-term interest rate, and real per capita income as the explanatory variables. No coefficient drivers are included.
(4) RC4: We use the short-term interest rate, real per capita income, and the growth of nominal income as the explanatory variables; the own-rate, the long-term interest rate, the inflation rate, and the unemployment rate are included as coefficient drivers.

†This section draws heavily on the works of Hondroyiannis *et al.* (2001a,b).
‡Because the quality of the time-varying coefficients allows the equation to pass through every data point even if the number of observations exceeds $n_t + 1$, the equation may be nonlinear.
§This means that β_{1t} is the effect of the true interest rate (r_t^*) on the true value of real money balance (m_t^*).
¶Swamy and Tavlas (2006) provide a formal definition of coefficient drivers. Hall *et al.* (2009) also indicate that coefficient drivers have two performances. First, they treat the correlation between the included explanatory variables and their coefficients. Second, they render us to decompose the coefficients of the RC estimation into their respective components.
⊥If e_{jt} and $\varepsilon_{\eta t}$ are assumed to be unrelated, then $E(\varepsilon_{\eta t}|e's) = E(\varepsilon_{\eta t}) = 0$ for each η and all t.

(5) RC5: We use the long-term interest rate, real per capita income, and the growth of nominal income as the explanatory variables; the own-rate, the short-term interest rate, the inflation rate, and the unemployment rate are included as coefficient drivers.
(6) RC6: We use the long-term interest rate, the short-term interest rate, and real per capita income as the explanatory variables; the own-rate, the growth of nominal income, the inflation rate, and the unemployment rate are included as coefficient drivers.

We now substitute equation (5) for equation (4):

$$\begin{aligned}\ln(m_t) = \pi_{00} &+ \sum_{j=1}^{b-1}\pi_{0j}e_{jt} + \pi_{10}\ln(r_t) \\ &+ \sum_{j=1}^{b-1}\pi_{1j}e_{jt}\ln(r_t) + \pi_{20}\ln(y_t) \\ &+ \sum_{j=1}^{b-1}\pi_{2j}e_{jt}\ln(y_t) + \pi_{30}\ln(g_{yt}) \\ &+ \sum_{j=1}^{b-1}\pi_{3j}e_{jt}\ln(g_{yt}) + \varepsilon_{0t} + \varepsilon_{1t}\ln(r_t) \\ &+ \varepsilon_{2t}\ln(y_t) + \varepsilon_{3t}\ln(g_{yt}). \qquad (7)\end{aligned}$$

In the RC estimation, there are three components in the stochastic equation, and hence we have to separate the direct effect from the total effect of the coefficient.† In our specification, we capture the direct effect contained in γ_{1t}, and the component $(\pi_{10} + \pi_{11}e_{1t} + \pi_{12}e_{2t})$ is the direct effect. By contrast, the indirect and mis-measurement effect is $(\pi_{13}e_{3t} + \pi_{14}e_{4t} + \varepsilon_{1t})$. The respective direct effects of γ_{2t} and γ_{3t} are $(\pi_{20} + \pi_{21}e_{1t} + \pi_{22}e_{2t})$ and $(\pi_{30} + \pi_{31}e_{1t} + \pi_{32}e_{2t})$, and the corresponding indirect effects are $(\pi_{23}e_{3t} + \pi_{24}e_{4t} + \varepsilon_{2t})$ and $(\pi_{33}e_{3t} + \pi_{34}e_{4t} + \varepsilon_{3t})$.

While the time-varying coefficients are represented by the Kalman filter, we consider it appropriate to use maximum likelihood estimation (MLE) to calculate the coefficient for each period. We continue with the specification of equation (7) and the determinants. In equation (7), the variance is

$$\begin{aligned}\text{Var}(\varepsilon_{0t}) = \sigma^2_{\varepsilon_{0t}} &= \sigma_0^2 + r_t^2\cdot\sigma_1^2 + y_t^2\cdot\sigma_2^2 + g_{yt}^2\cdot\sigma_3^2 \\ &+ 2r_ty_t + 2y_tg_{yt} + 2r_tg_{yt}. \qquad (8)\end{aligned}$$

Let Γ be the vector of parameters, where $\Gamma = \{\pi_{00}, \pi_{01}, \ldots, \pi_{34}, \varepsilon_{0t}, \varepsilon_{1t}, \ldots, \varepsilon_{3t})$. The logarithmic likelihood function then becomes

$$\begin{aligned}l(\Gamma|r_t,y_t,g_{yt}) = \text{const} &- 0.5\sum_{t=1}^{T}\log\sigma^2_{\varepsilon_{0t}} \\ &- 0.5\sum_{t=1}^{T}[\ln(m_t) - \pi_{00} - \pi_{01}e_{1t} - \cdots - \pi_{11}e_{1t}\ln(r_t) \\ &- \pi_{12}e_{2t}\ln(r_t) - \cdots - \varepsilon_{0t} - \varepsilon_{1t}\ln(r_t) - \cdots \\ &- \varepsilon_{3t}\ln(g_{yt})]/\sigma^2_{\varepsilon_{ot}}, \qquad (9)\end{aligned}$$

where const is the constant, and l is the maximum likelihood function. The maximum likelihood estimation of Γ is obtained by solving

$$\frac{\partial l}{\partial \pi_{ij}} = 0. \qquad (10)$$

3. Data description and empirical results

3.1. Data

All series are obtained from the National Statistics Data Bank as well as Chang-Hwa Bank, which is one of the five largest banks in Taiwan and has complete long-term data. Data for M2 (broad money), the own-rate, and short-term interest rates are obtained from central bank data included in National Statistics. We use the time period 1982Q1 to 2006Q4, because the empirical data are available during this period of time.

Gross domestic product (GDP hereafter) data are taken from the national income data statistics of National Statistics. Data on the inflation rate are taken from the price data statistics of National Statistics, and unemployment rate data are obtained from the workforce data statistics included in National Statistics. In order to take into account the longest periods available, the data on long-term interest rates are obtained from Chang-Hwa Bank. M2 is used to measure the total amount of money, is deflated by the consumer price index (2000 = 100), and is transformed into real money balances. We use real per capita income for y_t and deflated by the consumer price index (CPI) for the year 2000. For short-term interest rates, the one-month deposit rate is used as a proxy variable, and the long-term interest rate is represented by the three-year time deposit rate of Chang-Hwa Bank. The nominal income growth is evaluated by the growth rate of GDP at current prices. The unemployment rate is measured based on the number of unemployed as a percentage of the total population over the age of 15 that makes up the workforce. We use 2000 as the base year to calculate the inflation rate. The own-rate is defined as $OR(\text{own} - \text{rate}) = (h/ms)\cdot r^s$,‡ where r^s is the short-term interest rate, h is high-powered money, and ms is the broad money stock. This measurement means that the interest earned by r^s is multiplied by ms except for h.

3.2. Random coefficient estimation

Table 1 presents the values of the RC estimated using equation (7). The specification of the regression is estimated from 1982Q1 to 2004Q4 and RMSE is estimated from 2005Q1 to 2006Q4. Each coefficient is the average of every individual and each has a t-statistic. In order to assess the performance of the coefficient drivers, we provide six different regressions. RC1 to RC3

†The direct effect has its own straightforward and real-world interpretation.
‡Rates of return may be conveniently categorized as own rates, because the deposits begin earning interest; besides, the opportunity cost appears to be related to the own rates.

Table 1. The elasticity of random coefficient models.

	Without coefficient drivers			With coefficient drivers		
Variable	RC1	RC2	RC3	RC4	RC5	RC6
Constant	−3.271	−2.369**	0.101***	2.395**	1.327	5.412***
	(−0.181)	(−2.248)	(3.557)	(2.209)	(0.647)	(9.855)
Short-term R	−0.003***		−0.038	−0.002		−9.90E−05
	(−4.269)		(−1.572)	(−1.396)		(−1.434)
Long-term R		−0.175*	−0.045		−0.005**	−0.006***
		(−1.781)	(−0.403)		(−2.114)	(−3.517)
Log *y*	2.305***	1.452***	0.881***	1.08E−08***	0.001***	3.43E−05
	(4.317)	(2.424)	(2.747)	(3.333)	(3.381)	(0.542)
Log *gyt*	−0.021***	−0.016***		−4.52E−05***	−0.001	
	(−3.943)	(−2.846)		(−3.228)	(−1.510)	
RMSE	0.060	0.004	0.005	0.002	0.061	0.001

Numbers in parentheses are *t*-values. *Indicates statistical significance at the 10% level. **Indicates statistical significance at the 5% level. ***Indicates statistical significance at the 1% level. RMSE is the root mean square error. Short-term R denotes the short-term interest rate. Long-term R denotes the long-term interest rate. Log *y* is real per capita income. Log *gyt* denotes nominal income growth. 'Without coefficient drivers' refers to the equation without coefficient drivers, while 'With coefficient drivers' refers to the equation with coefficient drivers. The coefficients are the averages of the individual time-varying coefficients from 1982Q1 through 2006Q4. The prediction is the out-of-sample forecast, based on the data for 1982Q1 to 2004Q4 being used to forecast 2005Q1 to 2006Q4.

consist of the estimates without coefficient drivers, while RC4 to RC6 are the estimates with coefficient drivers.

Table 1 sheds light on the coefficients for the interest rate. For RC1, the coefficient for the short-term interest rate is −0.003. For RC2, the coefficient of the long-term rate is −0.175. This may be compared with Fang (1992), who obtains a value of −0.062 using the conventional form specified by Goldfeld (1973), who adopts the short-term interest rate to estimate the coefficient for Taiwan. Huang *et al.* (2001) obtain an estimate of −0.082 for the elasticity of the short-term interest rate.

Our estimates are at the low end of the spectrum compared with the estimates of Fang (1992) and Huang *et al.* (2001). This result may also be compared with Lee and Guo (1999), who adopt a fractional cointegration approach to analyse the short-term interest rate and obtain a value of −0.174, which is close to our long-term estimated value, but significantly different from our short-term estimated value. Huang and Shen (2002) use a one-month deposit interest rate to estimate the cointegration model and obtain an elasticity of −0.422. The value provided by Huang and Shen (2002) appears to be the highest based on our previous review of the literature. Even though the values of the coefficients are very small, they are still consistent with the hypothesis of a negative elasticity of the interest rate.

By turning to RC3, even the short-term addition to the long-term interest rate −0.038 is still a low one. The estimates of the coefficient for real per capita income (y_t) of RC1 to RC3 range from 0.881 to 2.305, and the value obtained by Fang (1992) is 0.197, while that of Lee and Guo (1999) is 1.567. Other relevant studies, including that of Huang *et al.* (2001) who use a co-integrating equation, indicate that the estimate for the elasticity of income is 1.596. However, the value obtained by Huang and Shen (2002) is 10.572, which differs significantly from our results. The values obtained in the previous papers fall within the bounds of our estimates.

We now turn our attention to RC4 to RC6—those coefficients with coefficient drivers—which are significantly different from the equations without coefficient drivers. When using four coefficient drivers, the elasticity of the interest rate declines markedly. For RC4, the short-term interest rate is −0.002, which is lower than the figure calculated for RC1. This indicates that the elasticity will be lower when coefficient drivers are considered, and, furthermore, the same situation can be observed with RC6.

For RC6, the elasticity of the short-term interest rate is -9.90×10^{-5}, and the long-term interest rate variables may be summed up to −0.006, a figure that is smaller than the sum of the coefficients for RC3. However, in particular, the *t*-values of the short-term interest rate coefficients for RC4 and RC6 are insignificant. Moreover, the elasticity of real per capita income also becomes negligible. For RC4, the elasticity of y_t is 1.08×10^{-8}. For RC5 and RC6, the y_t values for the coefficients are 0.001 and 3.43×10^{-5}, respectively. Therefore, the value estimated by the RC model with four coefficient drivers is quite small, but it still has a positive effect on the demand for money. By turning to nominal income growth (g_{yt}), it can be seen that the coefficient serves as an index for us to judge the relationship between the demand for money and the variable that is composed of the price level and some nominal interest rate effects. One should particularly be aware of the nominal interest rate, as it contains the change in the price level and the real interest rate. The coefficients of nominal income growth for RC4 and RC5 are -4.52×10^{-5} and −0.001, respectively.

The predictable performance to which we should pay more attention concerns the RMSEs. As shown in table 1, the RMSEs produced by equations RC1 to RC3 are very close to those produced by equations RC4 to RC6. Hondroyiannis *et al.* (2001a) are of the opinion that the RMSEs produced by the equations with coefficient drivers need not be compared with those produced by

Table 2. Random coefficient estimates of direct effects and total effects.

	Constant Gamma	Interest rate		Real per capita income		Nominal income growth	
		Gamma	Direct effect	Gamma	Direct effect	Gamma	Direct effect
RC4	2.395**	−0.002	−0.354**	1.08E−08***	0.606***	−4.52E−05***	0.161**
	(2.209)	(−1.369)	(−2.278)	(3.333)	(4.231)	(−3.228)	(2.323)
RC5	1.327	−0.005**	−0.108***	0.001***	0.106***	−0.001	−0.283**
	(0.647)	(−2.114)	(−3.185)	(3.381)	(10.595)	(−1.510)	(−2.205)

Numbers in parentheses are *t*-values. *Indicates statistical significance at the 10% level. **Indicates statistical significance at the 5% level. ***Indicates statistical significance at the 1% level. Gamma (γ_{1t}, γ_{2t}, and γ_{3t}) is the total effect of elasticity.

the equations without coefficient drivers. However, the RMSEs are at a low level, so that we can use this estimation model to predict and provide an explanation for the demand for money. In table 1 of the RMSEs ranging from RC1 to RC6, the one with the highest value is RC5 (0.061), while RC6 has the best performance among all of these equations, for the RMSE is only 0.001. In particular, RC6 is the equation closest to the original specification of the demand for money regarding the interest rate and real income per capita.

Table 2 separates the direct effect from the total effect (Gamma; γ_{1t}, γ_{2t}, and γ_{3t}) of the coefficients for RC4 and RC5. The difference between the original specification and the estimation of the RC is that the error terms represent the indirect effects in the traditional method, whereas in the RC estimation approach the coefficient drivers are used to analyse the direct and mis-measurement effects. Moreover, because RC4 and RC5 specifications include four coefficient drivers, it is possible to extract the direct effects from the total effects. The main purpose behind separating the direct effect is to observe the influence of the own-rate in the procedure. In the RC approach, the own-rate with either the long-term interest rate or the short-term interest rate takes the coefficient drivers into consideration to evaluate the direct effects of the coefficients in equations RC4 and RC5. As shown in table 2, the *t*-values of the direct effects are more significant than the total effect. The results reveal that the own-rate is a necessary determinant that we should take into account in the demand for money function.

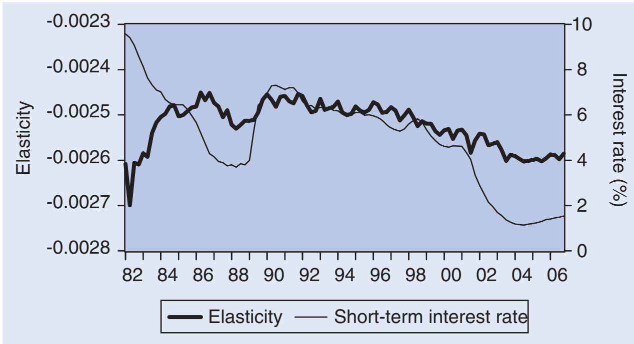

Figure 1. Short-term interest rate elasticity for RC1.

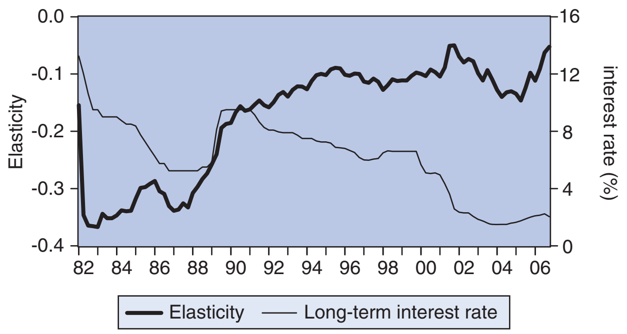

Figure 2. Long-term interest rate elasticity for RC2.

3.3. The time-varying behavior

Figure 1 shows the profile of the elasticity and the trend of short-term interest rates. Figure 2 depicts the elasticity of the long-term interest rates and the trend itself. The left side represents the elasticity and the right side represents the interest rate in the figures. RC1 and RC2 do not deal with the effects of the coefficient drivers. As shown in figure 1, the elasticity of the short-term interest rate changes within a narrow spectrum from −0.024 to −0.026. However, when the trend is closely monitored, it appears to descend slowly from 1989 to 2006, indicating that the influence of the short-term interest rates becomes smaller after the 1990s.

In figure 2 the elasticity of the long-term interest rates changes within a wide spectrum with respect to the short-term interest rates. However, the trend of the elasticity still moves upward gradually. By comparing figure 1 with figure 2, it can be seen that they both change slightly within a limited spectrum around 1989.

From figures 3 and 4, we observe the profiles of time-varying coefficients with coefficient drivers. In figure 3, the elasticity of the direct effect is very different from the elasticity of the short-term interest rate. The elasticity of the interest rate is negatively correlated with the movements along the demand for money, while the elasticity of the direct effect has some points in its profile that are positive. The use of the own-rate is similar to the use of the interest rate as a coefficient driver for influencing the elasticity variation of the dependent variables and money demand. A comparison between the interest rate and the direct effect in figure 3 indicates that there is an opposite trend.

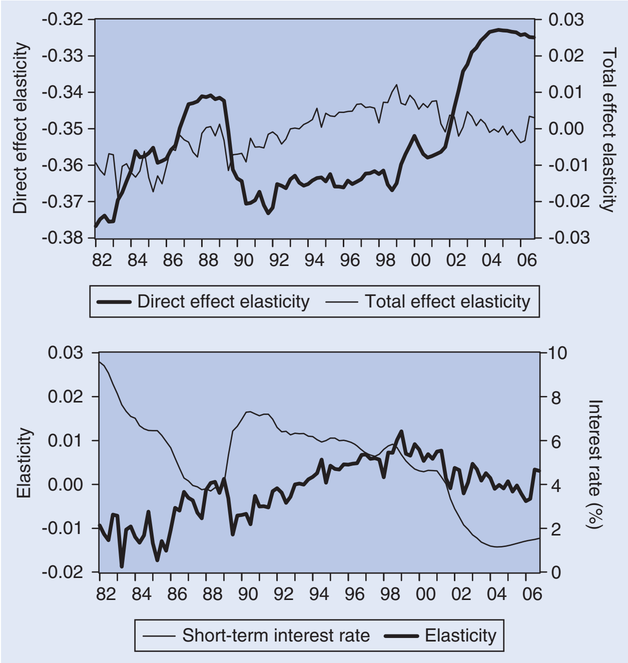

Figure 3. Total effect and direct effect for short-term interest rate elasticity for RC4.

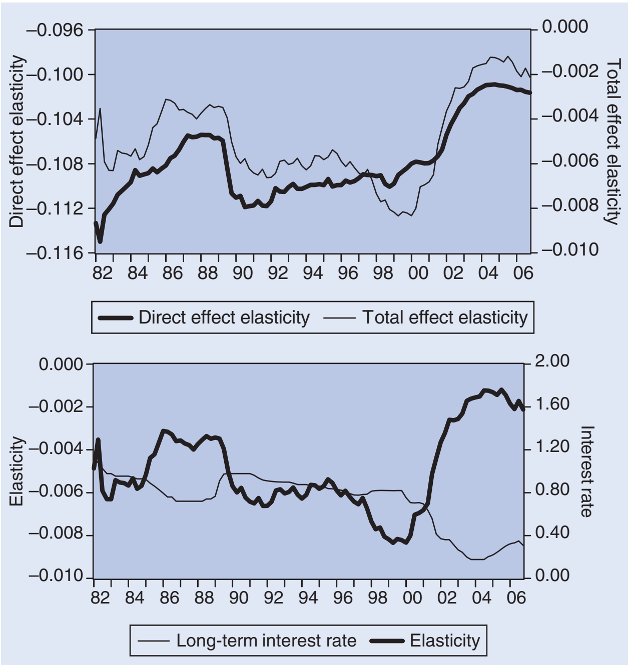

Figure 4. Total effect and direct effect for long-term interest rate elasticity for RC5.

We can see the same situation in figure 4. In addition, the trends in the elasticity of the long-term interest rate and the elasticity of the direct effect move closely together in figure 4. By analysing figures 3 and 4 in depth, figure 3 shows that the elasticity of the direct effect fell from −0.34 in 1989 to −0.378 in the early 1990s, which is a big margin, and the direct effect of figure 4 fell from −0.106 in 1989 to −0.112 in the early 1990s. The situation mentioned above is the same as the elasticity of the total

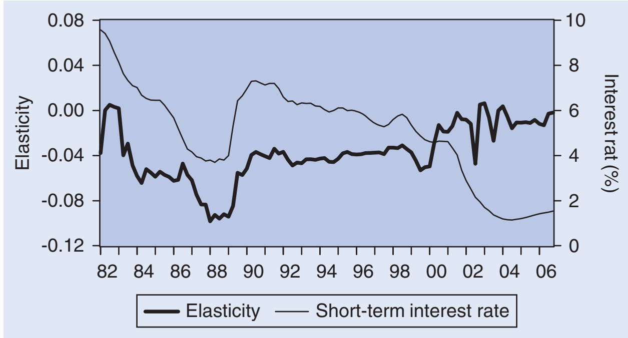

Figure 5. Short-term interest rate elasticity for RC3.

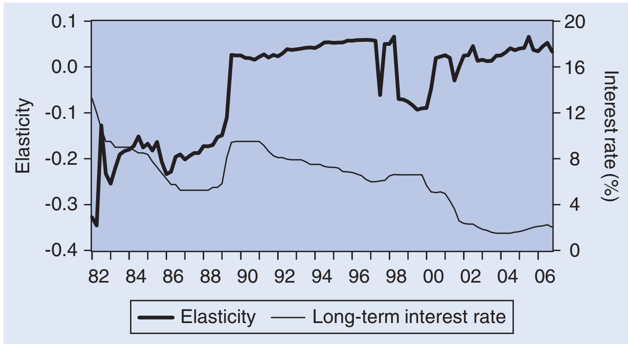

Figure 6. Long-term interest rate elasticity for RC3.

effect in figures 3 and 4. The direct effect elasticities demonstrate much less volatility over time than the total effect elasticities, indicating that the impact of specification errors on the time profiles has some substance.

In actual fact, the central bank substantially adjusted the current account reserve ratio from 23% to 27% in 1989, and commercial banks started to implement selective credit controls on the capital asset market simultaneously. Under these circumstances, with the resulting deflation, the proprietors of capital assets had to raise cash, which resulted in investors and enterprises being encouraged to sell their own stockholdings in exchange for money.

Figures 5 and 6 show the respective elasticity of long-term and short-term interest rates for RC3 without coefficient drivers, and figures 7 and 8 depict RC6 with coefficient drivers. Some of the different specifications in RC3 are as follows: (1) we do not use coefficient drivers in this model; (2) variable g_{yt} is omitted from the expression; and (3) long-term and short-term interest rates become variables simultaneously. For RC3, short-term and long-term interest rates had a similar inclination in the 1980s, and they both exhibited an upward trend after 1989. For RC6, for the same reasons, the profile of the elasticity of the short-term interest rate cannot be reached. However, when compared with the elasticity of the long-term interest rate, the direct effect is the exception that goes against the trend. In addition, the time trend of the interest rate elasticity from 1990 to 1997 is stable. We find evidence of this inclination not only in figures 3 and 4, but

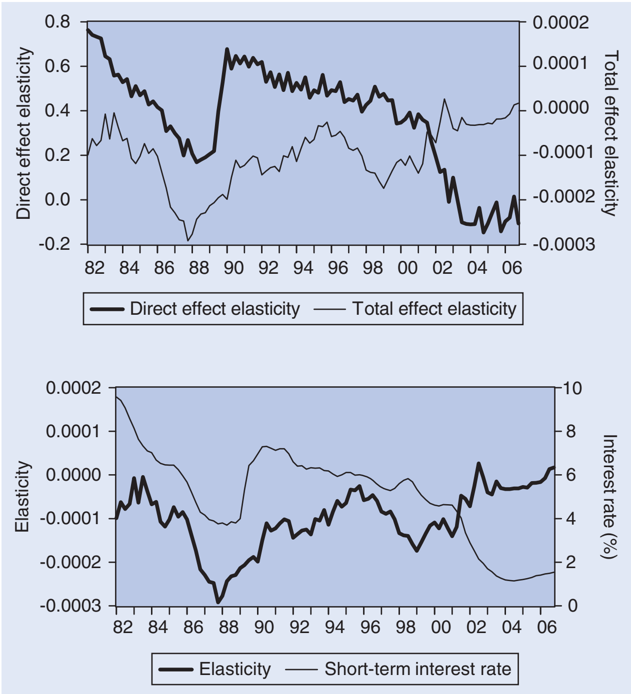

Figure 7. Total effect and direct effect for short-term interest rate elasticity for RC6.

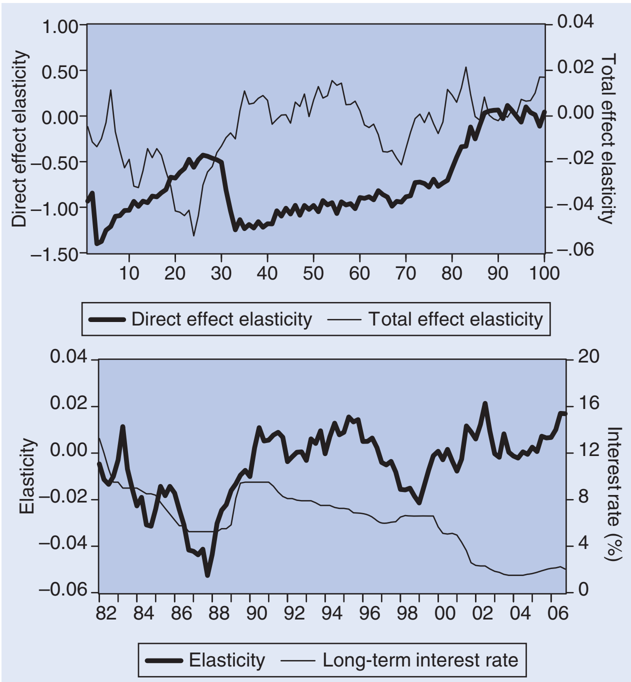

Figure 8. Total effect and direct effect for long-term interest rate elasticity for RC6.

also in figures 1 and 2. It is also fairly stable in figures 5 and 6 from 1990 to 1997.

Figures 5 and 6 show RC3 without coefficient drivers, and figures 7 and 8 depict RC6 with coefficient drivers. The other interesting topic is that the front sides of the trends in RC3 and RC6 are nearly perfectly matched, but they diverge after 2000. In 2000, the stock market—mostly in technology stocks—bubbled after the

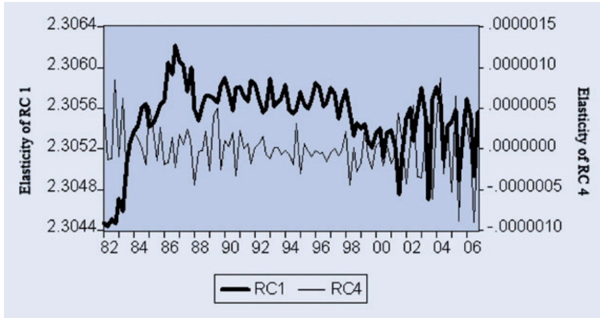

Figure 9. Income elasticity for RC1 and RC4.

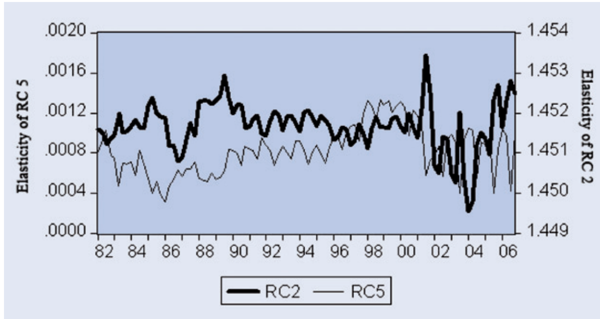

Figure 10. Income elasticity for RC2 and RC5.

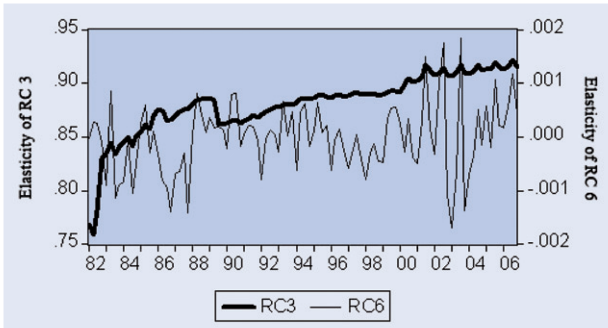

Figure 11. Income elasticity for RC3 and RC6.

presidential election in Taiwan, resulting in a political party transition. The end result brought about a sharp drop in the stock market index from 10 393 index points to 4555 index points. Because of this, the nation's economic system suffered a downward trend. The interest rate also declined by a large margin and the following unemployment rate played a key role in this regard. Economic adversity loomed and led to a higher unemployment rate, while there appeared to be a 'jump' in the trend. Both RC3 and RC6 and other specifications also went through a similar situation.

Income is an important factor in the estimation of the demand for money. Figures 9–11 show the profiles of the time-varying behavior corresponding to income elasticities for RC1 to RC6, respectively. The right-hand and left-hand vertical axes of the four figures are income elasticity values with respect to different specifications.

Table 3. Post-sample forecasts of random coefficient models.

Model	RC1	RC2	RC3	RC4	RC5	RC6
1987Q1 to 1989Q4	0.199	0.022	0.018	0.048	0.114	0.017#
1990Q1 to 1992Q4	0.200	0.014	0.013	0.035	0.147	0.013#
1993Q1 to 1995Q4	0.192	0.012	0.010#	0.036	0.152	0.017
1996Q1 to 1998Q4	0.183	0.010#	0.011	0.024	0.209	0.012
1999Q1 to 2001Q4	0.129	0.017	0.015	0.027	0.204	0.012#
2002Q1 to 2004Q4	0.163	0.026	0.022#	0.042	0.158	0.031
2005Q1 to 2006Q4	0.130	0.028	0.022	0.035	0.132	0.014#

Forecasts are based on equations estimated up until the forecast interval. For instance, forecasts for 1987Q1 to 1990Q4 are based on 1982Q1 to 1986Q4. #The smallest value of the forecast interval for RC1 to RC6. The prediction is out of sample. The values within the grid are RMSEs.

Some points are worth noting. First, the oscillation in income elasticity for each time trend is intense. Second, the variation of these elasticities is influenced by the variation in the coefficient drivers. When considering the coefficient drivers for RC4 to RC6, money demand is quite income inelastic. Third, there are relatively lower magnitudes of income elasticities in the specifications that include coefficient drivers than in those without coefficient drivers. According to figure 9, RC4 has the lowest value and greater variation in income elasticities, while RC1 has larger income elasticities that gradually increase over time. Fourth, all of the specifications are inclined to move upward. For example, RC3 in the initial period is 0.76 and then becomes 0.92 at the end of the period. While the specifications have coefficient drivers, the trend in income elasticity does not become very clear. However, the income elasticity values of RC4 to RC6 are increasing. Finally, possible structural breaks occur during the 1989–2001 period, which may be due to certain critical financial or economic events.

3.4. Post-sample forecasts

This section examines the performance of each specification from RC1 to RC6. The time series data are divided into four segments, beginning with 1987Q1 to 1989Q4, and the estimation is performed every three years for each interval. The measurement of this estimation is used as prior data in the forecast. For instance, the forecast for the period from 1987Q1 to 1989Q4 is estimated from 1982Q1 to 1986Q4. Table 3 shows the results.

As table 3 indicates, we compare the RMSEs of the specifications both with and without coefficient drivers, respectively. We investigate whether or not our use of different coefficient drivers has improved the forecasting accuracy. First, the performance of the RMSEs reveals that the specifications with coefficient drivers are superior to those without coefficient drivers except for RC5. Second, the RMSEs of RC6 are better than all the other specifications, relatively speaking. As shown in table 3, for the intervals 1987Q1 to 1989Q4, 1990Q1 to 1992Q4, 1999Q1 to 2001Q4, and 2005Q1 to 2006Q4, RC6 has four of the best performances over seven intervals. Consequently, we refer to the RMSEs for the period 1996Q1 to 1998Q4 and 1999Q1 to 2001Q4 through RC1 to RC6. As shown in the table, the RMSEs for RC4 and RC6 in this period are the lowest for the seven intervals. In retrospect, a local financial crisis occurred in 1997–1998 and its impact was felt for two years while a political party transition took place during this interval. These events resulted in a higher unemployment rate and the crisis continued to harm the country's economic prosperity. The financial sector was influenced by the crisis and gave further weight to predictions that the economy would perform poorly. This result also reveals that the different periods have different RC models.

Table 3, by comparing the performances of RC1 to RC3, presents the performance of RC3, which makes it the best equation in this group. As for the performances of RC4 to RC6, the performance of RC6 is the best in this group. After comparing the advantages of RC3 and RC6, it is found that the performance of RC6 is better than that of RC3. This comparison reveals that RC6 is the best equation in terms of making predictions.

When we turn to compare each interval, the results show that, for the period beginning from 1987Q1 and extending to 1992Q4, RC6 is a better specification for forecasting the money demand. From 1993Q1 to 1998Q4, we gain access to RC3 to make the forecast. From 1999Q1 to 2001Q4 and 2002Q1 to 2004Q4, we use RC6 and RC3 for these forecasts, respectively, while RC6 could be used for the prediction for the final interval. An interesting finding is that RC3 and RC6 have predictive performances that are superior to those of the others. Moreover, the short-term interest rate and the unemployment rate should be considered simultaneously, because the local financial crisis and the increased governmental devolution brought about instability in interest rates and resulted in a high unemployment rate. This finding also proves that the use of coefficient drivers is necessary.

4. Conclusions

The random coefficients estimation procedure is a new approach used to analyse the demand for money function. The reasons why we use the second-generation RC estimation method herein include the following. (i) Attempts are made to resolve certain restrictions such as time-invariant coefficients, the assumption that the true form is known, an error term used to proxy excluded variables, and the explanatory variables that exclude the measurement errors. (ii) According to Shen (1998), the demand for money function in Taiwan is not stable, and the true form is still unknown. Therefore, the nonlinear specification agrees with the situation that prevails in Taiwan. (iii) Since the appropriate determinants could not be decided, we have used the RC estimation method to relax the restrictions and to try to increase the accuracy of the prediction for money demand. In addition, we are able to observe the time-varying behavior of coefficients and explain the relationship between the determinants and monetary policy based on elasticity simultaneously.

Our main purpose is to use the RC model to estimate the demand for money function, find the trend of the elasticity and make forecasts, and then combine these with current events in Taiwan. The advantage of including the RC estimation is that it is robust to the functional form specification and omitted-variable and measurement error biases. The study covers the period from 1982Q1 to 2006Q4 for Taiwan. Real M2 is the dependent variable that is estimated using the main regressions for real income per capita, nominal interest rates, and nominal income growth. We adopt the own-rate, inflation rate, and unemployment rate as subsequent variables to estimate the demand for money.

The results indicate the following. (i) Compared with the results of the other studies, neither the elasticities of the interest rate nor those of income are much smaller than those of the previous studies. (ii) The time-varying behavior is observed while some break points occur in Taiwan such as in 1989 and 2001. Ever since 1980, some changes in the financial liberalization policy in Taiwan have been made, and so the trend in elasticity exhibits an upward inclination. The first main break point is in 1989, when the central bank implemented a succession of adjustments of interest rate policies and caused the elasticity of interest rates to move upward abruptly. In 1997–1998, a local financial crisis broke out in Taiwan due to many traditional and well-known enterprises suffering terrible financial conditions, such as Ban-Yu, a papermaking company, the Rui-Lian group, the An-Feng Steel company, the Chung-Shing textile group, Hong-Fu Construction and more than 20 other firms. The number of cases of illegal delivery and violations of contract amounted to billions of NT dollars. The financial problems resulted in financial crises in related corporations and led to unbalanced credit between related banks. Additionally, the political party in transition caused investors to lose confidence in the financial environment in 2000, and the stock market fell by a large amount. Therefore, the fluctuation in the unemployment rate caused the proxy to be a coefficient driver that affected the demand for money. As shown by the time profile, the trend rises after 2001 and is close to zero. Even for RC3 and RC6, the figure almost reaches zero. (iii) When we turn to discuss the errors of prediction, the specifications with coefficient drivers are better than the specifications that do not include coefficient drivers. In tables 1 and 2, the demonstration is consistent with our view, except for RC5. According to table 2, we find that the RMSEs for RC4 to RC6 in the period from 1996Q1 to 2000Q4 are higher than those of other periods. This is just the time when the Asian financial crisis broke out, and the coefficient drivers were the main factors that led to the margin of errors. (iv) The empirical findings show that the elasticity of the interest rate turns out to be positive in time profiles, and they are not consistent with the traditional view on money demand behavior.

Finally, there are two directions that could be extended for further discussion. One is the different coefficient drivers which can be used to re-evaluate the model. Since Taiwan is an open economic system, we can include the exchange rate in the model to observe the time-varying behavior of elasticity and the variation in prediction. Furthermore, we can compare the root mean square errors with the proper instrumental variables as a coefficient driver to estimate the model.

By comparing different models, we uncover the advantages and disadvantages of each model. We should take note of the traditional model, which is not inferior, because the ‘true form’ of the specification is known. The RC model itself relaxes the four restrictions on estimating the money demand, but this does not mean that the RC model is as complete as the true model. The different modeling approaches give rise to different abilities for prediction, for example Hondroyiannis *et al*. (2001b) and Brissimis *et al*. (2003) compare the vector error correction model with the RC model. This issue leaves plenty of room for further discussion in Taiwan.

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