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# Testing Long-Run Money Neutrality using Sweep-Adjusted Monetary Measures

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## Abstract

Although the proposition of Long-Run Money Neutrality is central in economics, the empirical evidence of the theorem is not entirely clear. The empirical methods have advanced during the last two decades, but few studies have emphasised the choice of monetary measure in the tests. The short-run relationship between conventional monetary aggregates and economic activity has broken down for the USA since the 1980s. One reason for this is the spread of so called sweep programs since 1994 which enable banks to circumvent reserve requirements by reclassifying funds. Particularly the narrow monetary aggregate M1 is distorted by these actions. Cynamon, Dutkowsky and Jones (2006b) propose sweep-adjusted monetary measures, and I use the sweep-adjusted aggregates M1s and M2s in a replica of the well-acknowledged test by King and Watson (1997). I compare the results of tests with conventional monetary aggregates with tests with sweep-adjusted aggregates. There are two findings of the study. Firstly, results show that the estimated long-run elasticity of real output with respect to money is farther from zero when sweep-adjusted money measures are used. This indicates that long-run neutrality is more likely to be rejected for sweep-adjusted monetary measures. Secondly, there is no clear difference between the results of tests with M1 and of tests with M2. From this, I consider it unlikely that further information is gained from the option to choose M1 instead of M2.

**Keywords:** Long-run neutrality, Monetary measures, Sweep programs, VAR-model.

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# 1 Introduction

The term Long-Run Neutrality refers to the proposition that permanent changes in nominal variables have no effect on real variables in the long run. This is a crucial idea in economics. Although most economists agree on the theory, the empirical findings are not unambiguous. The methods of testing the neutrality proposition have advanced since the end of the 1980s, much due to the Lucas-Sargent critique based on rational expectations. Lucas (1972) and Sargent (1971) recognised the necessity of non-stationary series if one wants to test whether a *permanent* shift in a nominal variable has an effect on a real variable (see e.g. King & Watson 1997, p. 74). Further, Lucas and Sargent pointed to weaknesses in the reduced-form econometric methods commonly used to test the neutrality proposition, and instead they argued for fully articulated behavioural models. Based on the critique, McCallum (1984) argued that a test of Long-Run Neutrality ought to be “conducted using cross-equation restrictions in a bivariate Vector Autoregressive (VAR) model” (see Tawadros 2007, p.14).

The most important application of neutrality theory is for money. Output stabilisation through monetary policy is built upon the idea that an unexpected rise in money supply will cause a short-run increase in real output through the Phillips-curve relationship. As the inflation expectations adjust, though, prices and wages rise, leaving real output unaffected in the long run. Suggested leading factors behind the transition mechanism are “sticky prices, sticky wages and imperfect competition” (see Starr 2005, p. 442).

It should be stressed that money measures have been de-emphasized in the US monetary policy (see e.g. Cynamon, Dutkowsky & Jones 2006a, p. 142; Carlson & Keen 1996, p. 15). Instead, the main target of the Fed, as well as of most other central banks, is the interest rate. One reason for the declining interest in money measures is the lacking short-run correlation between money and economic activity since the early 1980s (see Hafer and Wheelock 2001, p. 17). Modern models in monetary economics ascribe no influence to money once the interest rate is taken into account. Still the importance of money in monetary analysis is a

debated issue. Some studies do find empirical support for the influence of broad money measures on inflation and on real output (e.g. Hafer, Haslag & Jones 2007; Favara & Giordani 2002), while other studies relate the failing influence of money to non-proper monetary measures.

According to Teles & Zhou (2005, p.2), traditional aggregates of money may not longer be adequate for approximating transactions demand for money in the USA, because of banking deregulations since the 1980s and financial innovations in the 1990s. One major financial innovation of the 1990s is the use of so called sweep programs. Sweep programs enable banks to move a portion of funds from customer deposits or other checkable deposits into instruments with zero statutory reserve requirements (Cynamon, Dutkowsky & Jones, 2006b, p. 662). Since swept funds are reported differently, traditional money measures are underreported (Cynamon, Dutkowsky, Jones 2006a, p. 144). Cynamon, Dutkowsky and Jones (2006b) suggest measures of conventional money aggregates added by the swept funds that are not already included in the measures.

Although the question of the importance of money in monetary analysis is brought up in this study, the main focus is on the effect of the distortion of monetary aggregates by sweep programs on long-run money neutrality tests. Since most of these tests have been conducted for the USA, results may be inaccurate. The aim of this study is to investigate whether redefinitions of money have an impact on the results of long-run money neutrality tests for the USA. I conduct a test on US data based on King's and Watson's seminal article "Testing Long-Run Neutrality" (1997). Since sweep-adjustment improves the stability of M1 considerably, I use both the standard aggregate M2 and the narrower M1 as money measures. I compare the results of tests with sweep-adjusted aggregates with those of unadjusted ones. I find that long-run money neutrality is more likely to be rejected with sweep-adjusted money measures. Regarding the difference between M1 and M2, I do not find any clear pattern.

The study proceeds as follows. In the following section the theory of long-run money neutrality is briefly outlined and the relevancy of money is discussed. In this context, sweep programs are described and their impact on money measures is discussed. The final part of the chapter is an overview over previous long-run neutrality tests with emphasis on their results. In chapter 3 the King and Watson model is presented along with the data. The results of the tests are presented and analysed. Chapter 4 concludes.

## 2 Theory

### 2.1 Long-Run Money Neutrality

The definition of Long-Run Money Neutrality is that a permanent change (in the level) of the money stock does not have any long-run effect on (the level of) real output (see e.g. Westerlund & Constantini 2007, p 1). The reason for the inclusion of “(the level of)” is to distinguish the term from the related term *superneutrality* of money which means that a permanent change in the *growth rate* of money does not affect the level of real output (see e.g. Bullard 1999, p. 58). While neutrality of money is a widely accepted idea in monetary economics, superneutrality of money is more controversial and the only concern of this study is neutrality.

The Quantity Theory of Money identity links the quantity of nominal money to the general price level and to the real GDP:

$$mv \equiv py.$$

When  $v$ , the velocity of money, is stable a higher level of money supply accompanied by a proportionally higher price level, leaves the real money stock, and thus also the real GDP, unaffected. The *classical dichotomy* says that a shift in nominal money results in shifts in all nominal variables. In this case, real variables are unaffected. Today it is commonly accepted that the classical dichotomy fails. In nearly all macroeconomic models some imperfection is incorporated, either sluggish adjustment of prices or wages, or imperfect information about disturbances (see Romer 1993, p. 20). Nominal frictions, such as menu costs in price setting (e.g. reprinting catalogues), may, although being small, under imperfect competition and in combination with real rigidities, prevent firms from adjusting prices in response to changes in aggregate demand. Examples of sources behind real rigidities are market externalities and asymmetric information which may cause the marginal cost and the marginal revenue curves of firms to shift as aggregate demand varies (see Romer 1993, p. 11f.; Romer 2005, p. 294f. for an explanation of real rigidities).

There are several plausible explanations of the failure of neutrality. An important feature of Keynesian monetary theory is the belief that monetary disturbances cause changes in the interest rate which in turn will affect real output. In the long-run, though (in the absence of *hysteresis*), other variables ought to adjust in response to monetary disturbances. This is the basic intuition behind the proposition of long-run neutrality. However, empirical investigation shows that the impact of monetary disturbances on real variables can be prolonged and it is therefore of interest to empirically test the validity of the long-run money neutrality proposition.

Usually, we believe that only unexpected changes to money supply have (short-run) effect on real variables. Anticipated changes are already incorporated by the market participants when setting prices and wages. Bullard (1999, p. 58) writes that a permanent change in money supply can be thought of as an unexpected change to the money stock. Before going into the methodology and the results of long-run neutrality tests, I will highlight the discussion of the relevancy and the measurement of money in modern monetary analysis.

### 2.1.1 Is money relevant in monetary analysis?

In the predominant New Keynesian models monetary policy normally affects inflation and output through the interest rate (see e.g. Favara & Giordani 2002, p. 1f.). Money often enters into the models through the money demand equation, and changes in money supply are only thought to offset movements in the money demand function (Ireland 2004, p. 970).

According to Leeper and Rousch (2003, p. 1217), the reasons for the disappearing influence of money in monetary policy analysis range from “declining correlations between conventional money measures and economic activity to the frustrating instability of empirical money demand specifications”. The trends of the velocity of money for conventional monetary aggregates in the USA have changed since the 1980s (see Hafer & Wheelock 2001, p. 2)<sup>1</sup>. Further, the correlation between the monetary base and the broader monetary aggregates has declined (see Burda & Wyplosz 2005, p. 213) which makes the targeting of monetary aggregates more difficult.

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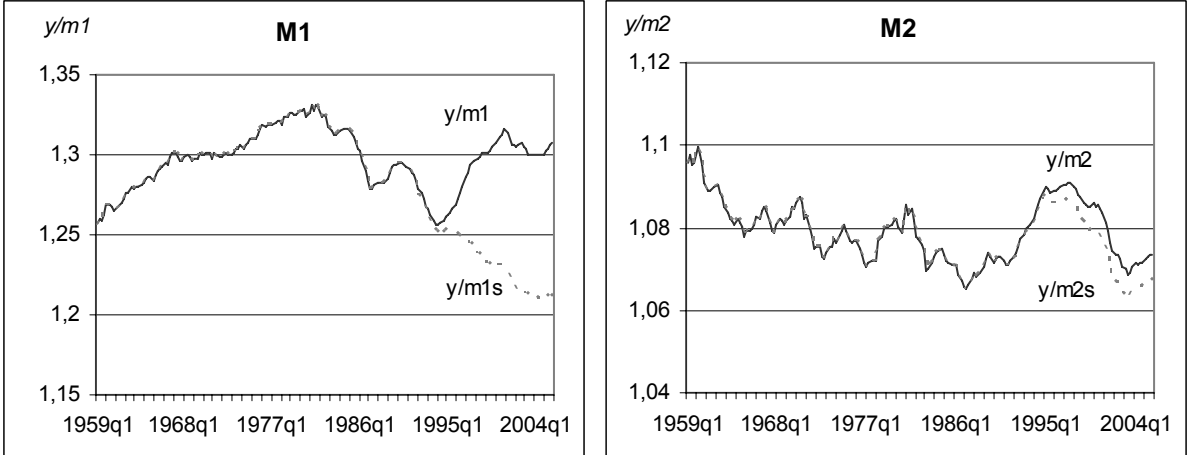
<sup>1</sup> The velocity of money should be predictable for the central bank to be able to monitor the money stock.

The instability of money demand is partly due to financial innovations. One solution to the unstable money demand functions is pointed out by Herwartz and Reimers (2006, p. 65):

“On the one hand, stable money demand equations have been derived for individual countries or currency areas, e.g. by Lütkepohl and Wolters (1999), Coenen and Vega (2001) and Calza and Sousa (2003). Given a stable equilibrium relationship between output, prices, interest rates and money, monitoring the latter may guard against excessive price instability. In addition, stability of money demand allows to control money growth by means of interest rate adjustments.”

Another way to deal with the lacking influence of money is to choose other monetary measures. The trend has been to switch from M1 to broader monetary aggregates, primarily M2. However, Bernanke and Mihov (1998, p. 5) criticise the use of broad measures of money as policy indicators since these may contain an endogenous, non-policy component in the case of a monetary policy rule that takes money demand shocks into account. The choice of monetary measures and the distortion of these measures caused by sweep programs is the topic of section 2.2. Figure 1 plots the income velocity of M1 and M2. The graphs also display the velocity of the aggregates when adjusted for sweep programs (denoted M1s and M2s).

**Figure 1. Income velocity\* for the USA, M1 and M2**



Source: Money stock: Federal Reserve Bank of St. Louis. GDP in current prices: Bureau of Economic Analysis. Sweep adjusted measures constructed by Cynamon, Dutkowsky and Jones (2006b).

\*Income velocity is calculated as nominal income (GDP) divided by the stock of nominal money.



In spite of the declining correlation between money and output since the early 1980s, there exists empirical support for including money in monetary policy models. The result of Leeper's and Rousch's (2003, see abstract) empirical study is that the way money is modelled significantly changes the size of output and inflation effects. Further, the findings of Hafer, Haslag and Jones (2007) as well as those of Favara and Giordani (2002) suggest that broad monetary aggregates contain information about future output. Nelson (2002, p. 668) refers to a study by Meltzer (2001) that argues for, and empirically shows that, with sufficiently sticky prices, the real money base (M0) influences aggregate demand even when the interest rate is controlled for.

Referring to previous studies, Leeper and Rousch (2003, p. 1220f.) present other arguments in favour of using money in monetary policy models:

- The informational role of money in forecasting the future nominal interest rate. "Ireland (2001a, 2001b) finds empirical support for including money growth in the interest rate rule for policy".
- The direct effect of money on aggregate demand. Nelson (2002) "posits that money demand depends on a long-term interest rate. Because long rates matter for aggregate demand, the presence of a long rate in money demand amplifies the effects of changes in the stock of money on real aggregate demand".
- Practical considerations. "If the Fed does not have contemporaneous information on inflation and output, but it does have observations on the money stock, then money may help the Fed infer current values of the variables it cares about directly".
- The role of transmitting monetary policy. "Goodfriend (1999, p. 414) argues that money plays a critical role even under an interest rate policy because '...credibility for a price-path objective stems from a central bank's power to manage the stock of money, if need be, to enforce that objective'."

In addition, a common critique against the use of the interest rate as policy measure is that there exist many interest rates (see Nelson 2002, p. 694 for a discussion).

To summarise, money is still important in the analysis of monetary economics, in spite of the fact that monetary aggregates are normally not the targets of the central banks. Up to date monetary aggregates might be a source of deriving information from money.

## 2.2 Sweep programs and adjusted monetary measures

### 2.2.1 Sweep programs

Although Commercial demand deposit sweeps have existed since the 1970s, sweep programs are a phenomenon mainly of the past decade. The idea of a sweep account is to invest excess available funds that otherwise would not have generated any interest into interest-bearing accounts. Two types of sweep programs can be distinguished: retail sweep programs and commercial demand deposit sweep programs (I will use the abbreviation commercial DD sweep program). Since the introduction of retail sweep programs in 1994, the use of sweep programs has spread rapidly (Cynamon, Dutkowsky & Jones 2006b, p. 662). The size of swept funds in the USA totalled approximately \$850 billion during October 2002 (Cynamon, Dutkowsky & Jones 2006a, p. 143). By comparison, M1 for the same period amounted to approximately \$1220 billion.

In a retail sweep program, banks move funds into money market deposit accounts (MMDA), which are short-term interest bearing accounts (see Campbell R. Harvey's Hypertextual Finance Glossary). Banks thereby circumvent reserve requirements. Since retail sweeps do not change customers' perceived amount of transaction deposits, banks are unlikely to have passed along the earnings to them (Anderson & Rasche 2001, p. 56). Under commercial demand deposit sweep programs banks establish interest-bearing investment accounts that are linked to their customers' commercial demand deposit account (Cynamon, Dutkowsky & Jones 2006b, p.662; 2006a, p. 143). Contrary to retail sweeps, commercial DD sweeps are undertaken with the direct permission from the account holders. Banks benefit among other things from charging fees and customers receive interest without active intervention (Cynamon, Dutkowsky & Jones 2006b, p. 664; Jones, Dutkowsky & Elger 2005, p. 489).

## 2.2.2 Monetary measures

The most common measures of money are M1, M2 and M3. Traditionally, M1 has been used as the main measure of transactions money (MacLean 2001). The stable upward trend of the velocity of M1 in the USA disappeared in the 1980s. Cynamon, Dutkowsky and Jones (2006b, p. 663) find distortions of this measure by almost 70 percent in 2003 due to sweep programs. M2 includes MMDA, and thereby funds in retail sweep programs. The distortion caused by sweep programs in 2003, found by Cynamon, Dutkowsky and Jones (2006b), was not more than five percent for M2. Nevertheless, M2 velocity deviated from its long-run trend in the 1990s (see Hafer & Wheelock 2001, p. 2). M3 captures all of the linked investment accounts associated with commercial DD sweep programs (Jones, Dutkowsky & Elger 2005, p. 486; Cynamon, Dutkowsky and Jones 2006, p. 662). Broader measures, though, contain additional interest-bearing assets, and moving to broader aggregates may therefore not be a satisfying solution (Jones, Dutkowsky & Elger 2004, p. 486).

A complementary measure of money that is proposed by Carlson and Keen (1996) and Teles and Zhou (2005) among others is MZM (money zero maturity). A benefit of this measure is that it includes institutional money market mutual funds ( MMMF)<sup>2</sup> (Cynamon, Dutkowsky & Jones 2006b, p. 666). The deviation from the constructed sweep-adjusted monetary measure is also the lowest for MZM; only three percent in 2003 (ibid, p. 668). However, a study by Duca and VanHoose (2004), referred to by Cynamon, Dutkowsky and Jones (2006a, p. 143), suggests that this measure has also encountered velocity problems in the 2000s, possibly due to substitution into funds other than MMMF. A classification of the conventional monetary aggregates provided by Carlson and Keen (1996) plus M2M is presented in Table 1.

**Table 1. Conventional Monetary Aggregates**

<b>M1</b>	Currency + Demand deposits + Other checkable deposits + Traveler's checks
<b>M2</b>	<b>M1</b> + Savings deposits (including MMDAs) + Small time deposits + Retail MMMFs
<b>M2M</b>	<b>M2</b> – Small time deposits
<b>MZM</b>	<b>M2</b> + Institutional MMMFs – Small time deposits
<b>M3</b>	<b>M2</b> + Large time deposits + Institutional MMMFs + Eurodollars + RPs

<sup>2</sup> Institutional MMMFs are “interest-bearing checkable accounts that allow holders to get around the zero-interest demand deposits restriction” (Teles and Zhou 2005, p. 11).

An important condition for money neutrality to hold, brought up by Westerlund and Constantini (2007, p. 20), is that the velocity of money is stable. They argue that “the long-run effect of an increase in money supply on prices could be dampened by a change in the velocity of money, brought about by for example institutional changes or financial innovations” (ibid). As suggested by the authors, one reason for rejecting the money neutrality proposition might be the fact that M2 is not broad enough to ensure that the velocity of money is stable.

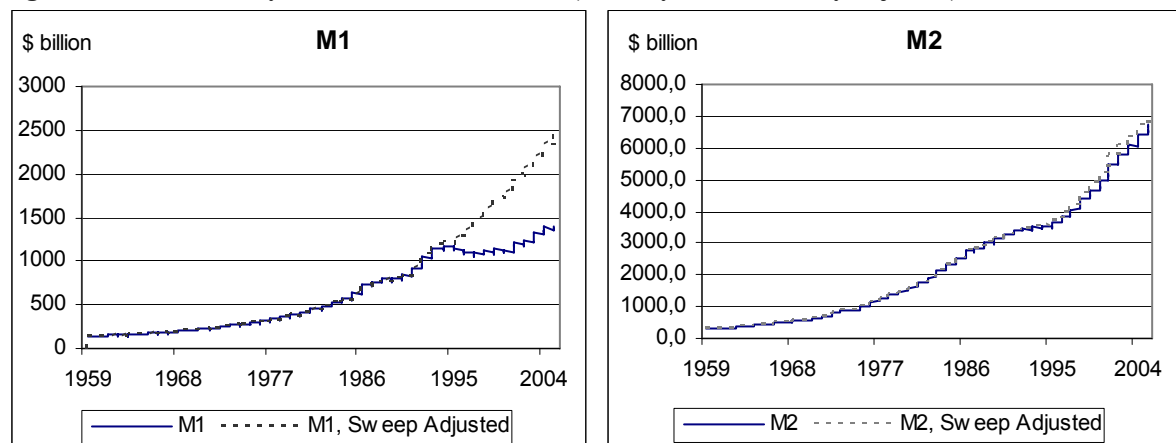
Jones, Dutkowsky and Elger (2005, p. 484) emphasize that for monetary measures to be useful in empirical investigation, it is crucial that they maintain conceptual consistency over time. To match the existence of sweep programs, researchers have proposed adjusted monetary aggregates (see ibid). Cynamon, Dutkowsky and Jones (2006b) add swept funds to the conventional money aggregates. The sweep-adjusted monetary aggregates are presented in Table 2.

**Table 2. Sweep Adjusted Monetary Measures proposed by Cynamon, Dutkowsky and Jones (2006b)**

<b>M1AS</b>	<b>M1A + (Retail Sweeps From Demand Deposits) + (Total Demand Deposit Sweeps)</b>
<b>M1RS</b>	<b>M1 + (Total Retail Sweeps)</b>
<b>M1S</b>	<b>M1 + (Total Retail Sweeps) + (Total Demand Deposit Sweeps)</b>
<b>M2S</b>	<b>M2 + (Demand Deposit Sweeps into Overnight Instruments) + (Demand Deposit Sweeps into Offshore Instruments) + (Demand Deposit Sweeps into Money Market Mutual Funds)</b>
<b>M2MS</b>	<b>M2M + (Demand Deposit Sweeps into Overnight Instruments) +(Demand Deposit Sweeps into Offshore Instruments) + (Demand Deposit Sweeps into Money Market Mutual Funds)</b>
<b>MZMS</b>	<b>MZM + (Demand Deposit Sweeps into Overnight Instruments) + (Demand Deposit Sweeps into Offshore Instruments)</b>

Figure 2 displays the graphs of M1 and M2, together with their sweep-adjusted counterparts.

**Figure 2. The US Money Stock from 1959 to 2005 (monthly, not seasonally adjusted)**



Source: Federal Reserve Bank of St. Louis. Sweep adjusted measures by Cynamon, Dutkowsky and Jones (2006b).

As seen in the graphs the main improvement from sweep-adjustment is assigned to M1 (see also figure 1). Since this aggregate is the one closest related to the monetary base which the central bank can control, the sweep-adjusted M1 is of special interest to this study.

Cynamon, Dutkowsky and Jones (2006b, p. 667, 669) collect annual data between 1991 and 2003 on commercial DD sweep programs from Treasury Strategies, a consulting firm in Chicago. The data is interpolated into monthly time series<sup>3</sup>. Monthly data on retail sweep programs is provided by the Federal Reserve and by Anderson (1997). Anderson (2003, p. 7) comments on the reported values that they may be inaccurate because banks are not required to continuously report the amounts of deposits involved in retail sweep programs.

## 2.3 Previous studies and tests of Long-Run Neutrality

Westerlund and Constantini (2007, p. 1) and Giordani (2001, p. 37) question the empirical evidence of long-run money neutrality. Although few tests have found evidence against the theorem, it should be stressed that they test only whether the hypothesis of long-run money neutrality can be *rejected or not*. Further, as pointed out by Bullard (1999, p. 58): “Empirical tests that convincingly documented departures from long-run monetary neutrality therefore

<sup>3</sup> For details regarding the method, see Cynamon, Dutkowsky and Jones (2006b, p. 669) and Jones, Dutkowsky and Elger (2005, p. 490 f.).

would be quite surprising (or quite suspect!) to monetary economists". We might therefore expect a certain bias towards not rejecting the null of long-run neutrality. Bullard (1999) provides a helpful survey of the studies made on the subject up to the end of the 1990s.

There are several difficulties associated with testing long-run money neutrality. One task is to isolate unanticipated monetary shocks from anticipated ones. A change in money can be caused by an exogenous policy action, but it may also be the response of a change in the money demand, for example caused by a rise in output. Cochrane (1998, p. 297) points to the fact that prolonged responses of output in response to changes in money may be the result of the initial shock, but if expected changes in money do have effect, the persistent response may also reflect the fact that a monetary expansion normally is followed by further expansion. Another difficulty is that the central bank reacts not only to the present economic stance, but also to the expected economic development (Romer 2005, p. 263). Since the interest rate is the preferred policy measure, Bernanke and Mihov (1998), simultaneously test the causality from money to the interest rate, known as the liquidity effect.

In the 1990s seminal papers were made by Fisher and Seater (1993) and King and Watson (1992, 1997). These researchers test the neutrality proposition using a bivariate VAR model. The vector autoregressive model captures the dynamics and the feedback of the system. Fisher and Seater (1993) discuss the implication of different orders of integration of the included variables. In principle, to be able to test long-run money neutrality, both money and real output should be nonstationary and thus subject to permanent changes (see e.g. Westerlund & Constantini 2007, p. 2). The case when the nominal variable is  $I(1)$  and the real variable is  $I(0)$  can be interpreted as a direct evidence of neutrality, though (see Fisher and Seater 1993, p. 405). Further, King and Watson (1992) argue that long-run neutrality tests in the context of a VAR model written in first differences are inefficient in the presence of cointegration between the variables (see Serletis & Koustas 1998, p. 7). The reason for this is that a cointegrating relationship implies an error-correction term which is omitted in the model. Serletis and Koustas (ibid) write: "In particular, if the output and money series are nonstationary and cointegrate, then a finite vector autoregressive (VAR) process in first differences does not exist and this is typically sufficient for rejecting long-run Neutrality". The approach of King and Watson (1997) which is the one used in this study, is explained more detailed in chapter 3.

King and Watson conduct their test on quarterly data from 1949 to 1990 for the USA and find no evidence against long-run neutrality. Fisher and Seater use data on money, prices and on nominal as well as real income between 1867 and 1975. The hypothesis of long-run monetary neutrality with respect to real output fails (Bullard 1999, p. 62). Fisher's and Seater's (1993) test of monetary neutrality with respect to real output has been replicated. In comments on the study, the sample is changed and long-run neutrality is not rejected. Further, Olekalns (1996) reproduces the empirical study using Australian data. Except for the broader money measure M3, Olekalns comes to the same result. Weber (1994) and Serletis and Koustas (1998) study several industrialised countries using the King and Watson methodology. Both studies are ambitious regarding unit root tests (see Bullard 1999, p. 67; Tawadros 2007, p. 25) and Serletis and Koustas further in cointegration testing (see Westerlund & Constantini 2007, p. 3f.). The findings support the theory of Long-Run Neutrality with exceptions of a few countries and narrow monetary aggregates. In general, broad measures of money show stronger evidence of long-run neutrality than narrower ones (see Westerlund & Constantini 2007, p. 20).

More recent studies take into account seasonality (Leong & McAleer 2000) and seasonal cointegration, as well as expanding the study field to include developing economies (e.g. Tawadros 2007). Generally the results support long-run neutrality (Leong and McAleer, like Olekalns, study Australia and reject the hypothesis of neutrality when using M3). An exception is the test by Westerlund and Constantini (2007) with panel cointegration tests covering 10 countries in which the null of long-run neutrality is rejected. The main contribution of Westerlund's and Constantini's study lies in their more advanced methods of cointegration testing. They point to the fact that a violation of the noncointegration assumption in the King and Watson approach implies a rejection of the neutrality proposition and because of the way the model is constructed, noncointegration is harder to reject (Westerlund & Constantini 2007, p. 2f.).

## 3 Empirical study

### 3.1 The model

To capture the mutual dependency between money and real output, it is necessary to construct a two-equation system. The vector autoregressive (VAR) model in its structural form consists of linear equations of each variable as a function of its own lagged values as well as of the contemporaneous and lagged values of the other variables in the system. The VAR model which was popularised by Sims (1980) is a multivariate extension of the autoregressive model and it can be seen as a kind of hybrid between univariate time series models and simultaneous equations models (see Brooks 2002, p. 330). The advantage of the VAR methodology is that it models the feedback of the system without necessitating the user to formulate a fully articulated behavioural model. The usual way to solve the system is to transform the structural VAR into a reduced-form model, i.e. a model with solely lagged variables on the right-hand side of the equations. Through deriving impulse response functions, it is possible to investigate the impact of shock innovations to the system. However, to recover the structural error terms one needs to impose restrictions on one or more of the coefficients. Since these restrictions are generally done on an ad hoc basis, the method has been criticised for being a-theoretic (see Enders 2004, p. 291).

To circumvent this problem, King and Watson (1992, 1997) work with a structural VAR model and they estimate regressions for different sets of restrictions. They start out with a bivariate vector moving average (VMA) model with the log of real output,  $y$ , and the log of the money stock,  $m$ , as variables (equations (1) and (2)). As mentioned, the order of integration of the variables is crucial for testing long-run neutrality. Since the variables are assumed to be integrated of order one and noncointegrated, the model can be written in first-difference form. The included variables are thereby stationary and the usual test statistics are valid.



$$\Delta y_t = \mu_y + \theta_{y\eta}(L)\varepsilon_t^\eta + \theta_{ym}(L)\varepsilon_t^m \quad (1)$$

$$\Delta m_t = \mu_m + \theta_{m\eta}(L)\varepsilon_t^\eta + \theta_{mm}(L)\varepsilon_t^m \quad (2)$$

$\varepsilon_t^\eta$  is a vector of shocks other than money,  $\varepsilon_t^m$  represents exogenous unanticipated changes in money and  $\theta_{ii}(L)\varepsilon_t^i = \sum \theta_{ii,j}\varepsilon_{t-j}^i$ . The long-run impact of a money shock can be investigated in this setting. King and Watson (1997, p. 74) explain:

“The permanent effect of  $\varepsilon_t^m$  on future values of m is given by  $\sum \theta_{mm,j}\varepsilon_{t-j}^m = \theta_{mm}(1)\varepsilon_t^m$ . Similarly, the permanent effect of  $\varepsilon_t^m$  on future values of y is given by  $\sum \theta_{ym,j}\varepsilon_{t-j}^m = \theta_{ym}(1)\varepsilon_t^m$ . Thus, the long-run elasticity of output with respect to permanent exogenous changes in money is

$$\gamma_{ym} = \theta_{ym}(1) / \theta_{mm}(1).”$$

In this setting, money is long-run neutral towards real output if  $\gamma_{ym} = 0$ . As explained by King and Watson (ibid) the model requires that the money series contain a unit root, since otherwise  $\theta_{mm}(1) = 0$ . The structural shocks other than money,  $\varepsilon_t^\eta$ , may also be chosen as  $\varepsilon_t^y$ ; shocks to output. With this rewriting, the notation is the same as in Serletis and Koustas (1998), and the proceeding paragraph is drawn from that study.

The VMA model can be inverted into a VAR model and the equation system (3) and (4) of order  $p$  is the working model in the test.

$$\Delta m_t = \lambda_{my}\Delta y_t + \sum_{j=1}^p \alpha_{my}^j \Delta y_{t-j} + \sum_{j=1}^p \alpha_{mm}^j \Delta m_{t-j} + \varepsilon_t^m \quad (3)$$

$$\Delta y_t = \lambda_{ym}\Delta m_t + \sum_{j=1}^p \alpha_{yy}^j \Delta y_{t-j} + \sum_{j=1}^p \alpha_{ym}^j \Delta m_{t-j} + \varepsilon_t^y \quad (4)$$

$m_t$  is the log of the money stock and  $y_t$  is the log of the real output. The residual terms  $\varepsilon_t^m$  and  $\varepsilon_t^y$  represent exogenous unexpected changes in money and output, respectively, while the coefficients  $\lambda_{my}$  and  $\lambda_{ym}$  correspond to the contemporaneous effect of output on the money supply and vice versa. The long-run effect can be derived through rewriting the equation-system:

$$\alpha_{mm}(L)\Delta m_t = \alpha_{my}(L)\Delta y_t + \varepsilon_t^m \quad (5)$$

$$\alpha_{yy}(L)\Delta y_t = \alpha_{ym}(L)\Delta m_t + \varepsilon_t^y, \quad (6)$$

where

$$\alpha_{mm}(L) = 1 - \sum_{j=1}^p \alpha_{mm}^j L^j, \quad \alpha_{my}(L) = \lambda_{my} + \sum_{j=1}^p \alpha_{my}^j L^j,$$

$$\alpha_{yy}(L) = 1 - \sum_{j=1}^p \alpha_{yy}^j L^j \quad \text{and} \quad \alpha_{ym}(L) = \lambda_{ym} + \sum_{j=1}^p \alpha_{ym}^j L^j.$$

With this representation the long-run multipliers are:

$$\gamma_{ym} = \alpha_{ym}(1) / \alpha_{yy}(1) \quad \text{and} \quad \gamma_{my} = \alpha_{my}(1) / \alpha_{mm}(1),$$

where  $\gamma_{ym}$  measures the long-run response of output to a permanent unit increase in money and  $\gamma_{my}$  measures the long-run response of money to a permanent unit increase in output.

The coefficients  $\lambda_{my}$  and  $\lambda_{ym}$  can be interpreted as the short-run elasticity of money with respect to output and the short-run elasticity of output with respect to money, respectively. The long-run multipliers  $\gamma_{my}$  and  $\gamma_{ym}$  can be interpreted as the corresponding long-run elasticities (see Westerlund and Constantini 2007, p. 5). If long-run money neutrality holds, the long-run elasticity of output with respect to money should equal zero.

Since the system is not identified, the researcher needs to make identifying assumptions. King and Watson firstly make the standard assumption that the structural error terms are uncorrelated and thus  $\text{cov}(\varepsilon_t^m, \varepsilon_t^y) = 0$ . The number of additional restrictions required to solve the system is  $(n^2 - n)/2$ , where  $n$  is the number of variables. One of the coefficients in the model must be fixed. The choice of restriction can be made on the basis of economic theory. The following restrictions have different economic interpretations:

- $\gamma_{ym} = 0$ . In this case, long-run neutrality of money is assumed.

- $\gamma_{my} = 0$ . Money is exogenous. This implies that shocks to the money stock are unanticipated (see Harris & Sollis 2003, p.185). The assumption that  $\gamma_{my} = 1$  is consistent with long-run price stability in the case of stable money velocity.
- $\lambda_{my} = 0$ , or  $\lambda_{ym} = 0$ . When either of the contemporaneous effects is zero, the model is recursive.

The logic of the method is that the estimated value of the long-run elasticity of output with respect to money should not be significantly different from zero when the other three elasticities take a reasonable range of values (see Westerlund and Constantini 2007, p. 2). By choosing a certain value for one of the three elasticities, it is possible to solve the model and check up on the obtained value of  $\gamma_{ym}$ .

### 3.1.1 Critique against the model

King and Watson (1997, p. 75) recognise the risk of omitted variables in their bivariate model. The advantage of the bivariate model is that the system is easy to work with, and that degrees of freedom are saved by the fact that the number of parameters is kept low. In their concluding remarks, King and Watson (1997, p. 95) point to four important weaknesses in their test. Firstly, the size of the data may be too small for the researchers to be able to identify the degree of integration with certainty. Secondly, the same critique is also applicable for the cointegration testing. Thirdly, the bivariate model is necessarily a simplification of the real macroeconomic world. Fourthly, King and Watson investigate three sets of neutrality propositions separately (long-run money neutrality, the long-run Phillips-curve and the long-run Fisher effect), although they are linked together.

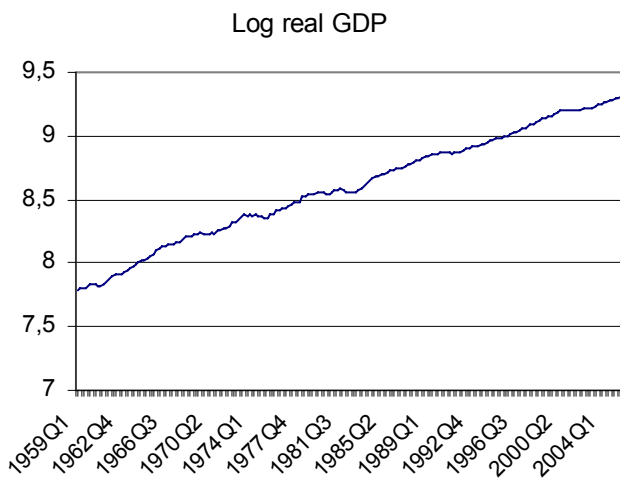
## 3.2 The data

Since neutrality deals with the effect on a real variable of a shift in a nominal variable, we are interested in figures of the nominal money stock (contrasted to real money balances, defined by Hafer, Haslag and Jones (2007, p. 950) as nominal money deflated by the GDP chain-weighted index) and of the real GDP. Quarterly data on the US real GDP is collected from US

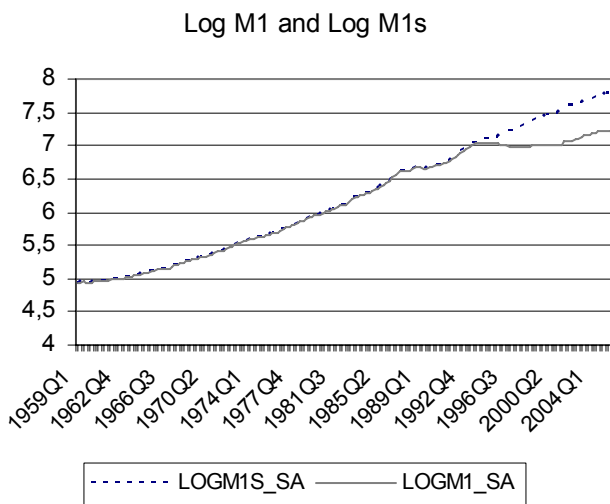
Bureau of Economic Analysis (bea.gov). The data consists of seasonally adjusted annual rates in chained dollars with 2000 as basis year. Figures of the money stock are provided by the Federal Reserve Bank of St. Louis. The adjusted money measures constructed by Cynamon, Dutkowsky and Jones are available at [www.sweepmeasures.com](http://www.sweepmeasures.com). The money stock data is on monthly basis, not seasonally adjusted. The sample period is January 1959 to December 2005. I will conduct tests with M1 and M2 and with the sweep-adjusted aggregates M1s and M2s and compare the results. An advantage of choosing US money data is that the economy is not as influenced by the rest of the world as smaller economies. A drawback with US money data is the large amount of US Dollars used by other countries and thereby not connected with US economic activity.

Although it is argued that seasonal adjustment distorts the data (see e.g. Harris & Sollis 2003, p. 63; Leong & McAleer 2000, p. 27), the use of seasonally adjusted data seems to be accepted. Because the values of real GDP are seasonally adjusted, I subtract the seasonal variation from the money measures using the X-12 function in E-Views. Through the default setting in E-Views the monthly money data is converted into quarterly frequency. All tests are conducted on quarterly data, the series being in their natural logarithm, henceforth denoted log. The graphs of the series together with descriptive statistics are presented in figure 3.

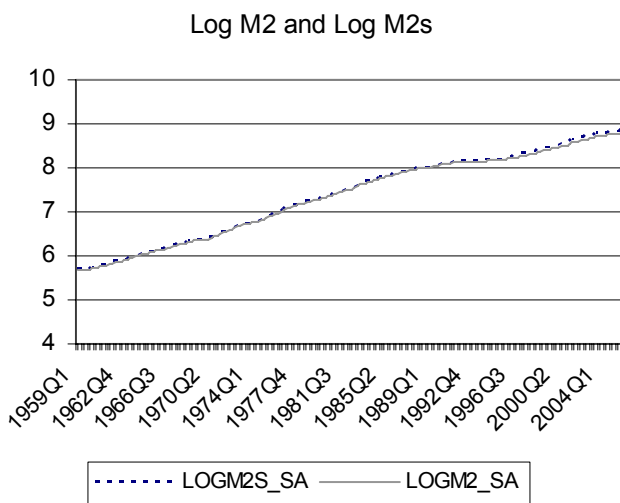
**Figure 3. Graphs and properties of the test series**



Mean	8,60
Jarque-Bera test of normality	9,25
Probability value (H <sub>0</sub> : normality)	0,0098



Mean	6,22
Jarque-Bera test of normality	14,50
Probability value (H <sub>0</sub> : normality)	0,0007



Mean	7,37
Jarque-Bera test of normality	14,59
Probability value (H <sub>0</sub> : normality)	0,0007

### 3.3 The test

**The first step** of the test procedure is to test for unit roots in the series. As mentioned, stationary series imply non-permanent shocks, preventing us from testing the neutrality proposition. Further, integration of order two is a non-desirable finding since it implies shocks to the *growth rate* of the series. In such case superneutrality can be tested, while neutrality can not.

Since unit root tests are known to have low power, it is common to use alternative tests. I choose to perform Augmented Dickey-Fuller tests together with KPSS tests. The KPSS test has the advantage of, in contrast to other unit root tests, testing the null hypothesis that the series are stationary. The unit root tests include both an intercept and a time trend, since the alternative hypothesis is that the series are trend-stationary. Results of both tests for the logged variables are presented in table 3.

**Table 3. Results of unit root tests of the log of the series**

<b>ADF test</b>	<b>GDP</b>	<b>M1</b>	<b>M1s</b>	<b>M2</b>	<b>M2s</b>	<b>Critical values</b>	
test statistic	-2,933	-1,172	-3,019	-0,479	-0,695	1%	-4,010
p-value	0,155	0,913	0,130	0,984	0,971	5%	-3,435
(H <sub>0</sub> : series is non-stationary)						10%	-3,141
<b>KPSS test</b>	<b>GDP</b>	<b>M1</b>	<b>M1s</b>	<b>M2</b>	<b>M2s</b>	<b>Critical values</b>	
test statistic	0,198	0,220	0,354	0,361	0,355	1%	0,216
(H <sub>0</sub> : series is stationary)						5%	0,146
						10%	0,119

As seen, all series are non-stationary at the five per cent significance level (only for the log of GDP the null of stationarity in the KPSS test cannot be rejected at the one per cent level). Further, tests of the first-differences of the series show that these are stationary and thus we can conclude that the series are integrated of order one. Therefore we can proceed with the neutrality test.

**The second step** of the procedure is to test for cointegration between the log of money and the log of real output. A cointegrating relationship implies a long-run relationship. The simplest way to test for cointegration is the Engle-Granger method which consists of an OLS regression of one variable onto the other and a unit root test of the residuals. Money is regressed onto real output and vice versa. The logic of the test is that a cointegrating

relationship between the variables implies a stationary combination, and the residuals from the regression should thus be stationary. There is no need to include an intercept in the unit root test, since the endogenous variable is the residual series from a regression (see Enders 2004, p. 336). Since the estimated residuals are derived through a minimization procedure and are thus more likely to be stationary, the usual Dickey-Fuller critical values are not applicable. Other difficulties are that we neither know which variable is endogenous nor whether the residuals are white noise (ibid, p. 345). Instead, it is recommended to apply the MacKinnon critical values. We might specify the linear relationship between money and output with an intercept and a deterministic time trend. An intercept should be included if the series have a non-zero mean. The result is sensitive to the inclusion of a time trend. Results of the Engle Granger test for cointegration with and without a deterministic trend are presented in table 4.

**Table 4. Engle Granger test for cointegration ( $H_0$ : no cointegration)**

Dependent variable	M1		M1s		M2		M2s	
	trend in ce	no trend	trend in ce	no trend	trend in ce	no trend	trend in ce	no trend
m	-1,892	-1,088	-3,842	-2,765	-0,501	-1,200	-0,817	-1,642
y	-2,895	-1,962	-3,885	-3,104	-3,017	-1,172	-3,017	-1,658

Values refer to ADF test statistics of the residual series from regressions  $y=\alpha+\beta m+\lambda t+\varepsilon$  and  $m=\alpha+\beta y+\lambda t+\varepsilon$ . MacKinnon (1990) critical values (5 %, 600 obs.): constant, no trend -3,3377, constant and trend -3,7809.

We cannot reject the null of no cointegration for any of the series M1, M2 and M2s. M1s is a borderline case. Regardless of which is the regressed variable in the M1s cointegration equation, the inclusion of a time trend yields low ADF test statistics and thus we are inclined to reject the hypothesis of no cointegration. However, I proceed with the test for M1s aware of the fact that the results must be treated with caution. I include a structural break in the first quarter of 1994 in the cointegrating relationships of M1 and of M2 (see table 5). Although the break is significant, the above conclusions do not change.

**Table 5. Engle Granger test for cointegration with a structural break 1994q1**

Dependent variable	M1		M2	
	trend, break in $\alpha$	no trend, break in $\alpha$ and $\beta$	trend, break in $\alpha$	no trend, break in $\alpha$ and $\beta$
m	-1,634	-2,367	-2.914	-2.345
y	-2,616	-2,777	-3.065	-2.631

Regressions, case 1:  $y=\alpha_1+\varphi_1*\alpha_2+\beta_1m+\lambda t+\varepsilon$  and  $m=\alpha_1+\varphi_1*\alpha_2+\beta_1y+\lambda t+\varepsilon$ .

Regressions, case 2:  $y=\alpha_1+\varphi_1*\alpha_2+\beta_1m+\varphi_2*\beta_2m+\varepsilon$  and  $m=\alpha_1+\varphi_1*\alpha_2+\beta_1y+\varphi_2*\beta_2y+\varepsilon$ .

Critical values (5 %): case 1: -4,99, case 2: -4,95.

**The third step** is to estimate the coefficients of the model. Dependent on which of the elasticities is prespecified the estimation procedure differs. When a contemporaneous effect is fixed, one of the equations (3) and (4) can be estimated by OLS, though letting the left-hand side variable subtracted by the fixed contemporaneous effect serve as the dependent variable. When either of the long-run multiplier is assumed known, one equation can be solved in the same way after having been rewritten. If, for example  $\gamma_{my}$  is fixed, equation (4) can be written as equation (7):

$$\Delta m_t - \gamma_{my} \Delta y_t = \beta_{mm} (\Delta m_{t-1} - \gamma_{my} \Delta y_t) + \sum_{j=0}^{p-1} \tilde{\alpha}_{my}^j \Delta^2 y_{t-j} + \sum_{j=0}^{p-1} \tilde{\alpha}_{mm}^j \Delta^2 m_{t-j} + \varepsilon_t^m, \quad (7)$$

where  $\beta_{mm} = \sum_{j=1}^p \alpha_{mm}^j$  (see Appendix 1 for an explanation). Equation (7) cannot be solved using OLS, because of the potential correlation between  $\Delta y_t$  and the error term. The set of regressors  $(\Delta m_{t-1} - \gamma_{my} \Delta y_t, \Delta^2 y_t, \Delta^2 y_{t-1}, \dots, \Delta^2 y_{t-p+1}, \Delta^2 m_{t-1}, \dots, \Delta^2 m_{t-p+1})$  is replaced by the set of instrumental variables  $\{\Delta y_{t-i}, \Delta m_{t-i}\}_{i=1}^p$ .

Both equations can then be solved using simultaneous equation methods. I choose the Seemingly Unrelated Regressions (SUR) method to estimate the equations. Whatever elasticity is assumed known, the second regression contains a contemporaneous regressor which is potentially correlated with the error term. The residual series from the OLS regression is used as instrument variable. This is a valid instrument because of the assumption that the structural shocks are uncorrelated. The regressions are shown in Appendix 2. All equations include an intercept. The lag length is two. In many cases, the second lag is insignificant, but for convenience all of the regression outputs are of the same order. It is of interest to keep the number of parameters low; yet one lag might be insufficient when dealing with quarterly data.

The calculated long-run impact elasticity of output with respect money,  $\gamma_{ym}$ , is plotted as a function of the respective prespecified elasticity. The range of values of the respective prespecified elasticity is chosen from King's and Watson's graphs. The standard errors of the models are complicated to derive, both because the long-run multipliers are nonlinear functions the regression coefficients, and because the residuals from another equation are used as a regressor in one of the equations (see King & Watson 1997, p. 96f. for a technical



discussion). Because of this, I display the calculated values without a confidence band. This is certainly a weakness in the analysis and it makes the comparison between the results of M1 and of M2 more difficult. However, still it is possible to compare the results of tests with sweep-adjusted measures with those of tests with unadjusted measures. The graphs are displayed in figures 4-6.

Figure 4. Calculated  $\gamma_{ym}$  as a function of  $\lambda_{ym}$ .

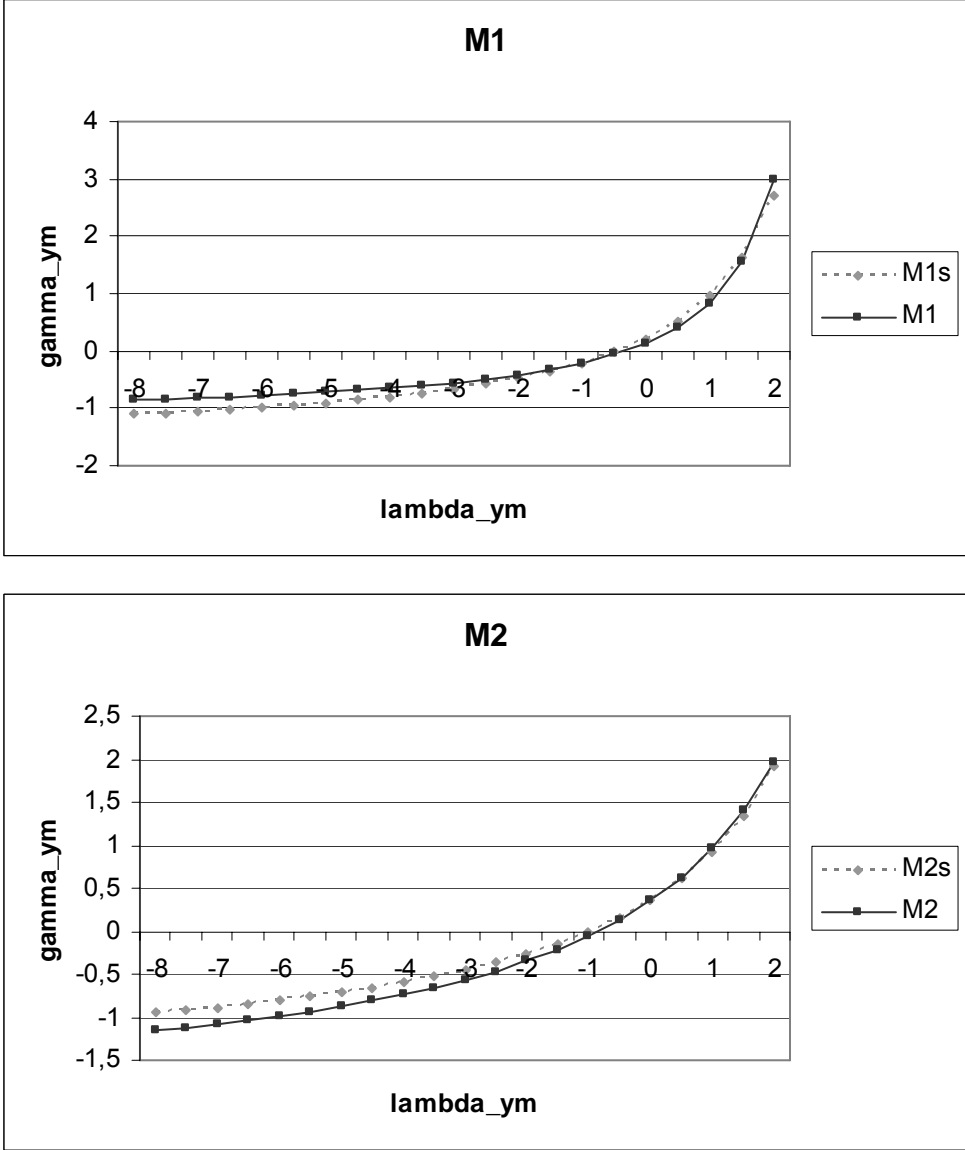


Figure 5. Calculated  $\gamma_{ym}$  as a function of  $\lambda_{my}$

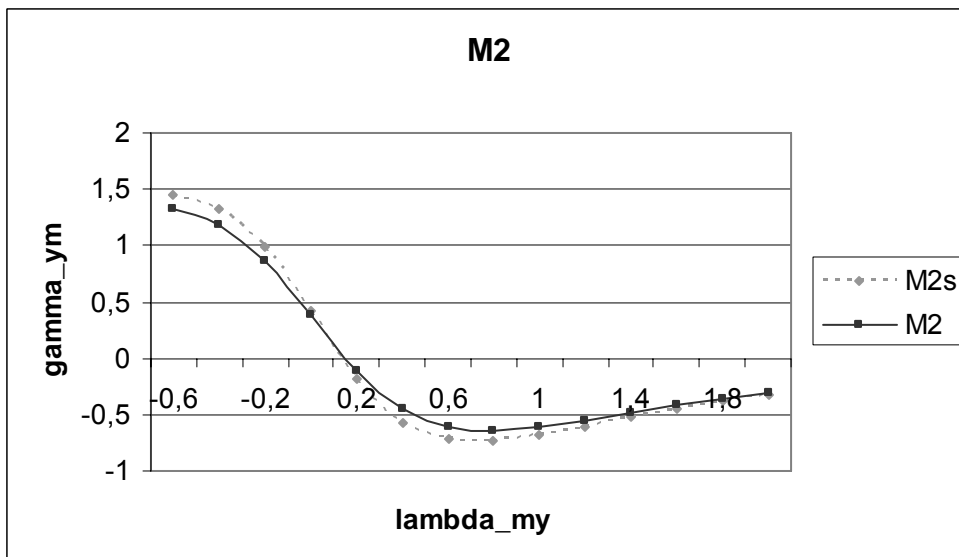
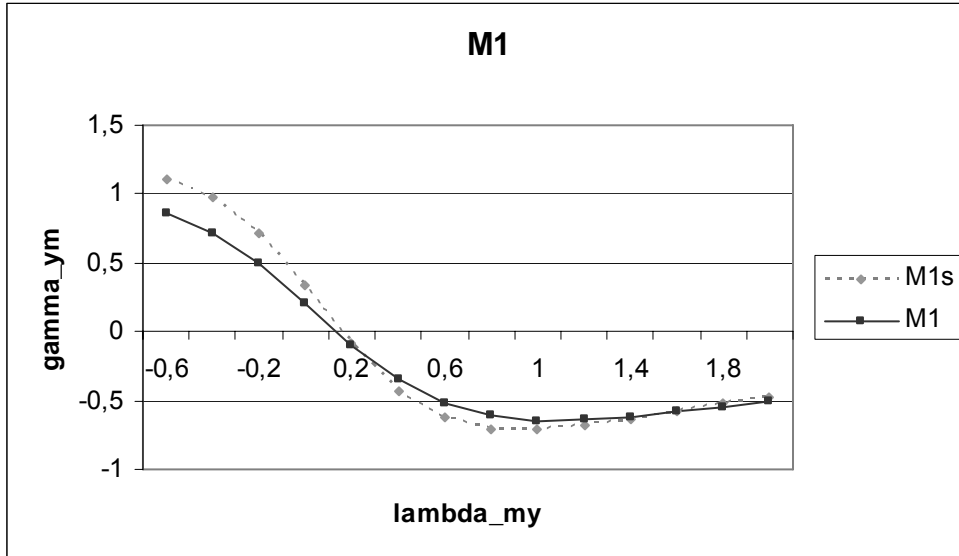
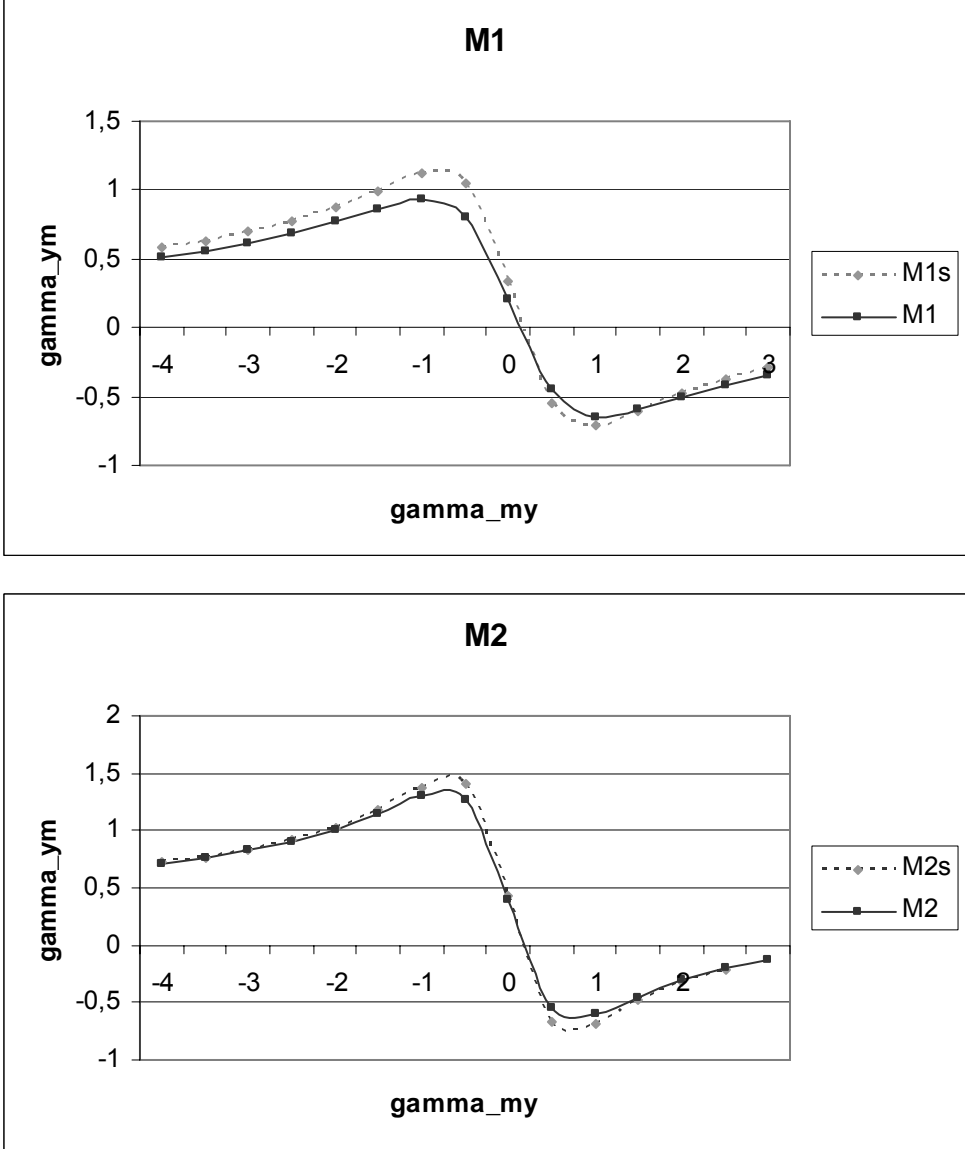


Figure 6.  $\gamma_{ym}$  as a function of  $\gamma_{my}$ .



The graphs of  $\gamma_{ym}$  as a function of  $\lambda_{my}$  and of  $\gamma_{my}$ , are somewhat different than the graphs presented by King and Watson (1997, p. 83). Figure 5 is corresponded by a likewise negative, but more dampened slope in King and Watson (1997). The most striking difference regards figure 6. In King and Watson, the calculated  $\gamma_{ym}$  as a function of  $\gamma_{my}$  is represented by a graph similar to the one previously mentioned. However, apart from the peaks in figure 6 the magnitudes of the estimated values in figures 5 and 6 seem to be within the boundary of the confidence intervals estimated by King and Watson (ibid.). It is important to note that King and Watson use a different sample period (1949-1990), and the aim of my test is thus not to investigate whether the results of King and Watson (1997) should be revised or not. Rather the results of King and Watson serve as a benchmark for my test.

### 3.4 Analysis

As mentioned, the absence of a confidence band around the calculated  $\gamma_{ym}$  prevents us from explicitly testing whether the proposition of long-run money neutrality fails or not.

Nevertheless we are able to compare the results of tests with conventional aggregates with those of tests with sweep-adjusted aggregates. Unfortunately, we cannot determine whether these differences are significant or not without standard errors. Although the analysis may seem poor in the light of this fact, the focus on money measures in tests of money neutrality is an important feature that is lacking in most of the previous tests, and still we can determine in what direction the sweep-adjustment affects test results. Since the stability, and thereby also the relevancy, of M1 is improved considerably when adjusting for sweep programs, an important implication of sweep adjustment is the possibility to use M1 in long-run money neutrality tests.

The first thing that can be observed in the graphs in figures 4-6 is that, in general, the values of the calculated  $\gamma_{ym}$  are farther from 0 for the sweep-adjusted aggregates. The exception is for M2 when  $\lambda_{ym}$  is constrained to be negative. Regarding the differences between the results of tests with M1 and those of tests with M2, there is no clear pattern. In the cases when  $\lambda_{my}$  and  $\gamma_{my}$  are prespecified the calculated absolute values of  $\gamma_{ym}$  are slightly larger if M2 is used instead of M1, while the opposite is true in the case when  $\lambda_{ym}$  is fixed. We also observe that the calculated long-run elasticity of output with respect to money lies around zero whenever the prespecified elasticities are zero.

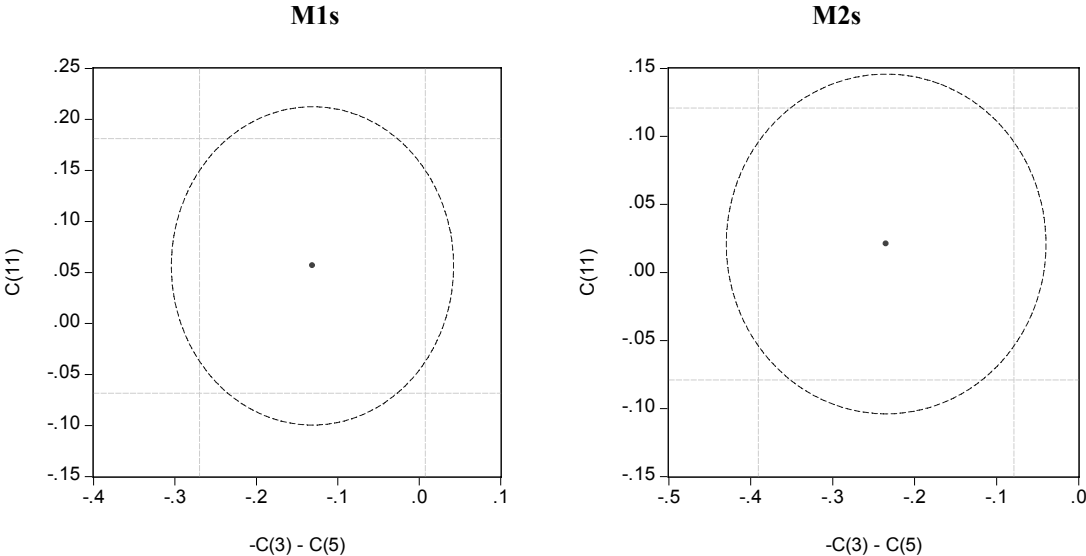
The important question is what values of the restricted elasticities are reasonable. King and Watson (1997, p. 81f.) discuss this question briefly. If output responds positively to a monetary expansion,  $\lambda_{ym}$  is positive. The parameter  $\lambda_{my}$  may be interpreted as the short-run elasticity of money demand if the central bank adjusts money in response to shifts in money demand. King and Watson argue that a sensible range for this parameter is between 0,1 and 0,6. I assume that a reasonable value for  $\gamma_{my}$  would be around 1, since  $\gamma_{my} = 1$  reflects long-run price stability if money velocity is stable.

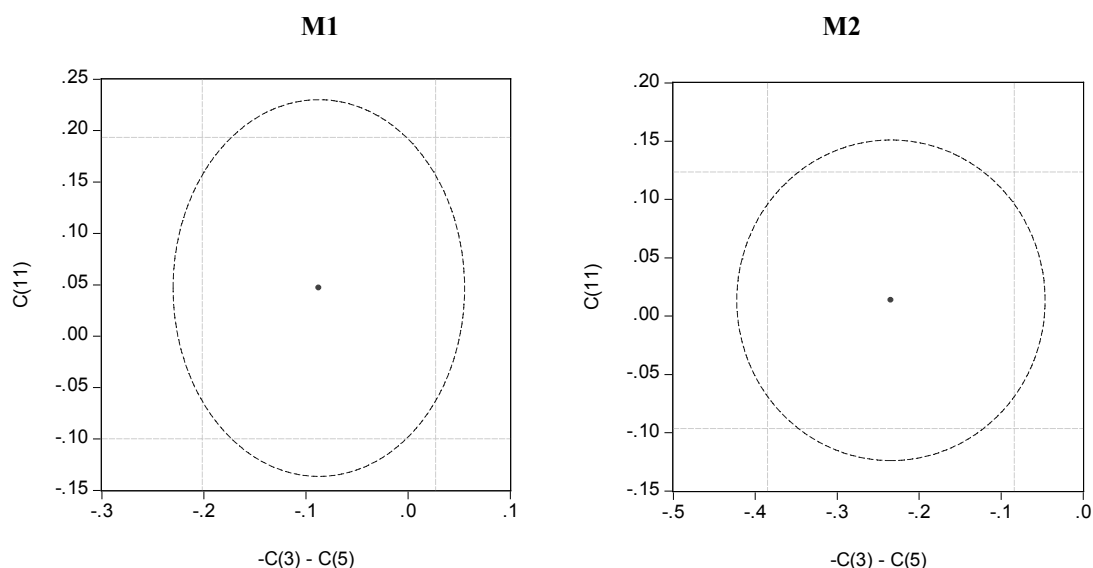
A comparison with the graphs and the included confidence intervals in King and Watson (1997, p. 83) indicates that the proposition of long-run money neutrality *cannot be rejected*

for any of the monetary measures in my test. Of the above suggested intervals, the only case when the estimated long-run elasticity of output with respect to money deviates from zero in a notable manner is when  $\lambda_{ym} > 0$ . However, the graph in King and Watson (ibid.) shows that the confidence interval grows along with the size of  $\gamma_{ym}$  when  $\lambda_{ym} > 0$ , so that the null cannot be rejected. In this context it should be noted that the differences between test results of sweep-adjusted and of conventional money measures are relatively small in relation to the confidence intervals.

Additional insight can be found by restricting  $\gamma_{ym} = 0$  (assuming money neutrality) and estimating  $\lambda_{ym}$  and  $\lambda_{my}$ . E-Views provides confidence ellipses of chosen parameters. Figure 7 displays the 95 per cent confidence ellipse of  $\lambda_{ym}$  and  $\lambda_{my}$  with estimates from the model when  $\gamma_{ym} = 0$ . The method is questionable since the regressions contain instruments, and since  $\lambda_{ym}$  and  $\lambda_{my}$  are recovered in the same way as  $\gamma_{ym}$  is constructed to restrict the model. At any rate, the confidence ellipses may give us a hint of what values are compatible with long-run money neutrality according to the model.

**Figure 7. 95 per cent confidence ellipses for  $\lambda_{ym}$  (-c(3)-c(5)) and  $\lambda_{my}$  (c(11)) when  $\gamma_{ym} = 0$**





Note:  $\lambda_{my}$  is calculated as the coefficient of the residual-instrument in eq. (2) in case 4 (Appendix 2) and  $\lambda_{ym}$  is calculated as the negative sum of the lagged effect of money on output in equation (1) in case 4 according to the formula:  $\gamma_{ym} = \alpha_{ym}/\alpha_{yy}$ .

The range of values of  $\lambda_{ym}$  and  $\lambda_{my}$  compatible with  $\gamma_{ym} = 0$  for each of the respective monetary aggregates are presented in table 6 (note that the presented values are extreme values referring to the case when the other parameter is at the dot in the ellipse).

**Table 6. Confidence intervals for  $\lambda_{ym}$  and  $\lambda_{my}$  when  $\gamma_{ym} = 0$  according to figure 7**

	<b>M1</b>	<b>M1s</b>	<b>M2</b>	<b>M2s</b>
$\lambda_{ym}$	-0,23 $<\lambda_{ym}<$ 0,05	-0,31 $<\lambda_{ym}<$ 0,03	-0,42 $<\lambda_{ym}<$ -0,04	-0,43 $<\lambda_{ym}<$ -0,04
$\lambda_{my}$	-0,13 $<\lambda_{my}<$ 0,23	-0,10 $<\lambda_{my}<$ 0,20	-0,13 $<\lambda_{my}<$ 0,15	-0,10 $<\lambda_{my}<$ 0,15

The values are more negative than we would expect from the above discussion. Further, surprisingly, the results do not differ considerably between the sweep-adjusted and the conventional aggregates. Because the sweep programs influence the monetary aggregates in a notable way only since 1994, the impact may disappear in a test of the entire sample. Randomly chosen Chow breakpoint tests of parameter stability in the OLS regressions do not yield highly significant results, though. An area of further research would be to compare results for different sub-periods. In the empirical study by Leeper and Rousch (2003) tests are conducted on models with and without money on US data for the period 1959-2001. The years 1979 and 1982 are critical in the study because monetary policy altered during that period and because of the banking deregulation that ensued in the USA.

## 4 Conclusion and summary

This study is about the distortion of monetary measures caused by sweep programs and its effect on long-run neutrality tests. A major implication of sweep-adjustment, as proposed by Cynamon, Dutkowsky and Jones (2006b), is the possibility to use the narrowest conventional monetary aggregate M1. I perform a test of long-run money neutrality on US data for the period 1959-2005 based on the approach of King and Watson (1997). I choose both the conventional monetary aggregates M1 and M2, and the sweep-adjusted aggregates M1s and M2s. Since I was not able to construct a confidence interval around the estimated long-run elasticity of real output with respect to money, the primary conclusions do not regard the rejection or non-rejection of the proposition of long-run neutrality, but rather in what way sweep-adjustment affects the results and whether there are obvious differences between the results of tests with M1 compared to tests with M2.

I find that the calculated long-run elasticity of real output with respect to money is farther from zero for the sweep-adjusted monetary aggregates than for the unadjusted aggregates. This implies that the proposition of long-run neutrality is more likely to be rejected when sweep programs are taken into consideration. However, since the calculations do not include standard errors, we cannot tell whether the effect of sweep-adjustment is significant. Regarding the comparison of the results of tests with M1 with tests with M2, no obvious differences are discerned. Based on this, I do not find that long-run neutrality tests are improved by the choice of M1 instead of M2. As before, though, we cannot draw any inferences with certainty from the sample without standard errors.

A more robust empirical test of long-run money neutrality with sweep adjusted monetary measures, would, apart from confidence intervals around the estimated long-run elasticity of real output with respect to money, include tests of different sub-periods. Shifts may have occurred in the early 1980s when financial deregulation was initiated in the USA, and in 1994, when retail sweep programs were introduced.

# Appendix 1

## Derivation of equation (7)

When  $\gamma_{my}$  is assumed known, King and Watson (1997, p. 96) rewrite equation (4) as:

$$\Delta m_t = \alpha_{my}(1)\Delta y_t + \beta_{mm}\Delta m_{t-1} + \sum_{j=0}^{p-1} \tilde{\alpha}_{my}^j \Delta^2 y_{t-j} + \sum_{j=0}^{p-1} \tilde{\alpha}_{mm}^j \Delta^2 m_{t-j} + \varepsilon_t^m, \quad (A1)$$

where  $\beta_{mm} = \sum_{j=1}^p \alpha_{mm}^j$ . The long-run multiplier in (A1) is  $\gamma_{my} = \alpha_{my}(1)/(1 - \beta_{mm})$ . Using the substitution  $\alpha_{my}(1) = \gamma_{my} - \beta_{mm} * \gamma_{my}$ , (A1) can be written as (7).



## Appendix 2

### Estimation methods

Estimation procedure:

Equation (1) is estimated using OLS. Equation (1) and (2) are then estimated simultaneously by Seemingly Unrelated Regression (SUR) method.

Regression estimations:

Case 1:  $\lambda_{ym}$  is known.

$$(1) \Delta y_t - \lambda_{ym} \Delta m_t = c_1 + c_2 \Delta y_{t-1} + c_3 \Delta m_{t-1} + c_4 \Delta y_{t-2} + c_5 \Delta m_{t-2} + \varepsilon_t^y$$

$$(2) \Delta m_t = c_6 + c_7 \Delta y_{t-1} + c_8 \Delta m_{t-1} + c_9 \Delta y_{t-2} + c_{10} \Delta m_{t-2} + c_{11} \hat{\varepsilon}_t^{y,OLS} + \varepsilon_t^m$$

Case 2:  $\lambda_{my}$  is known.

$$(1) \Delta m_t - \lambda_{my} \Delta y_t = c_1 + c_2 \Delta y_{t-1} + c_3 \Delta m_{t-1} + c_4 \Delta y_{t-2} + c_5 \Delta m_{t-2} + \varepsilon_t^m$$

$$(2) \Delta y_t = c_6 + c_7 \Delta y_{t-1} + c_8 \Delta m_{t-1} + c_9 \Delta y_{t-2} + c_{10} \Delta m_{t-2} + c_{11} \hat{\varepsilon}_t^{m,OLS} + \varepsilon_t^y$$

Case 3:  $\gamma_{my}$  is known.

$$(1) \Delta m_t - \gamma_{my} \Delta y_t = c_1 + c_2 \Delta y_{t-1} + c_3 \Delta m_{t-1} + c_4 \Delta y_{t-2} + c_5 \Delta m_{t-2} + \varepsilon_t^m$$

$$(2) \Delta y_t = c_6 + c_7 \Delta y_{t-1} + c_8 \Delta m_{t-1} + c_9 \Delta y_{t-2} + c_{10} \Delta m_{t-2} + c_{11} \hat{\varepsilon}_t^{m,OLS} + \varepsilon_t^y$$

Case 4:  $\gamma_{ym}$  is known.

$$(1) \Delta y_t - \gamma_{ym} \Delta m_t = c_1 + c_2 \Delta y_{t-1} + c_3 \Delta m_{t-1} + c_4 \Delta y_{t-2} + c_5 \Delta m_{t-2} + \varepsilon_t^y$$

$$(2) \Delta m_t = c_6 + c_7 \Delta y_{t-1} + c_8 \Delta m_{t-1} + c_9 \Delta y_{t-2} + c_{10} \Delta m_{t-2} + c_{11} \hat{\varepsilon}_t^{y,OLS} + \varepsilon_t^m$$

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### **GDP:**

US Bureau of Economic Analysis ([www.bea.gov](http://www.bea.gov)).

### **M1s and M2s:**

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