Institut für Wirtschaftsforschung Halle

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January 2010 No. 2

IWH-Diskussionspapiere

*IWH-Discussion Papers*

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# Money and Inflation: The Role of Persistent Velocity Movements*


## Abstract

While the long run relation between money and inflation is well established, empirical evidence on the adjustment to the long run equilibrium is very heterogeneous. In the present paper we use a multivariate state space framework, that substantially expands the traditional vector error correction approach, to analyze the short run impact of money on prices. We contribute to the literature in three ways: First, we distinguish changes in velocity of money that are due to institutional developments and thus do not induce inflationary pressure, and changes that reflect transitory movements in money demand. This is achieved with a newly developed multivariate unobserved components decomposition. Second, we analyze whether the high volatility of the transmission from monetary pressure to inflation follows some structure, i.e., if the parameter regime can assumed to be constant. Finally, we use our model to illustrate the consequences of the monetary policy of the Fed that has been employed to mitigate the impact of the financial crisis, simulating different exit strategy scenarios.



**Keywords:** Velocity, multivariate state space model, inflation, money

**JEL classification:** E31, E52, C32



* The authors are indebted to Oliver Holtemöller, Dominik Weiss and Katja Drechsel for valuable comments and discussions.

# Geld und Inflation: Die Rolle beständiger Veränderungen der Geldumlaufsgeschwindigkeit


## Zusammenfassung

Während die Langfristbeziehung zwischen Geld und Inflation in der Literatur als weitgehend gesichert gilt, ist empirische Evidenz bezüglich der Anpassung an das Langfristgleichgewicht ambivalent. Im vorliegenden Papier verwenden wir ein multivariates Zustandsraummodell, das eine erhebliche Erweiterung des traditionell verwendeten Fehlerkorrekturrahmens darstellt, um die Konsequenzen von Geldmengenveränderungen für die Inflation zu analysieren. Wir tragen auf dreierlei Weise zur bestehenden Literatur bei: Erstens unterscheiden wir Veränderungen der Umlaufsgeschwindigkeit, die dauerhafter Natur sind — z.B. ausgelöst durch institutionelle Entwicklungen — von vorübergehenden Veränderungen. Zweitens überprüfen wir ausführlich, inwiefern die Beziehung zwischen Geldmenge und Inflation stabil ist, d.h. ob das Parameterregime als konstant unterstellt werden kann. Schließlich illustrieren wir auf der Grundlage unserer Schätzungen die Konsequenzen der jüngsten Geldpolitik der Federal Reserve, die eingesetzt wurde, um die Folgen der Finanzmarktkrise abzumildern, unter verschiedenen Annahmen bezüglich der Exit-Strategie.



**Schlagworte:** Umlaufsgeschwindigkeit, multivariates Zustandsraummodell, Inflation, Geldmenge

**JEL-Klassifikation:** E31, E52, C32

# 1 Introduction

Central banks all over the world increased money supply substantially in reaction to the current financial crises. While this does not cause inflationary pressure at the moment due to the current business cycle environment, the question arises if and when excess liquidity endangers price stability.

While the long run relation between money and inflation is well established, empirical evidence on the transmission mechanism is very heterogeneous. Partially, this is due to the high dependency of the adjustment process on the current economic and institutional environment. This in turn induces strong volatility in the transmission from money to prices that renders current and lagged money growth ineffective in explaining inflation.[1] Contrarily, Vector Error Correction Models (VECM) that account for deviations from the long run relation of money, prices, and production, have been more successful in explaining inflation via monetary indicators for a limited set of countries, albeit results differ strongly.[2] These approaches have most prominently been used in the recent money demand literature. Especially P-Star-Models that have been proposed by Hallman, Porter & Small (1991) have been successful in explaining inflation in the Euro area.[3] However, the P-Star-approach has not yet been very successful in identifying the relationship between money and inflation in the US (Rudebusch & Svensson 2002).

While the present paper is focused on explaining inflation, it relies heavily on the long run assumptions that are commonly used in the money demand literature, where the long run validity of the quantity theory, is often taken for granted. Besides integrating the strands of literature from inflation forecasting and money demand, the present paper contributes to the literature in three ways:

First, we use several methods to distinguish changes in money velocity that are due to institutional developments and thus do not induce inflationary pressure and changes that reflect transitory movements in money demand. Most notably we develop a multivariate state space model of velocity that allows a decomposition

1 There are, however, some recent contributions that argue that money growth does indeed affect inflation significantly if the correct measure of domestic monetary aggregates is chosen. (Aksoy & Piskorski (2006))

2 See, eg. Shapiro & Watson (1988), Christiano, Eichenbaum & Evans (1999), and references therein.

3 See, among others, Kaufmann & Kugler (2008), Svensson (2000).

within a structural model, without applying restrictions on the causes of velocity development.

Second, we analyze whether the high volatility of the transmission from monetary pressure to inflation follows some structure, i.e. if the parameter regime can assumed to be constant. In our paper we focus on a state space approach that accounts for time varying adjustment coefficients very flexibly for this purpose. Our findings suggest that the adjustment of prices to money is either constant or that the volatility of possible movements is mostly random. Since this implies that monetary policy that follows a short term horizon is basically impossible, even if the long run nature of the money-price relation is taken into account. Thus, our results support the claim for monetary policies that do not attempt to react to minor shocks to prices or output.

Finally, we use our model to illustrate the consequences of the monetary policy that has been employed to mitigate the impact of the financial crisis. In addition to the forecast that is derived using the past behavior of the central bank, we simulate alternative exit strategies.

The remainder of the paper is structured as follows. Section 2 further outlines the underlying theoretical concepts and relevant literature. Section 3 introduces the dataset that is used for our estimations. Section 4 presents the methodologies that are used for velocity filtering. The corresponding VECM results are found in section 5. Section 6 expands the core model with some robustness tests and accounts for nonlinearities. Section 7 describes different policy scenarios based on our multivariate model. Section 8 concludes.

# 2 The link between money growth and inflation

Assuming that the long run equilibria of GDP and money are not dependent on money, the quantity theory of money predicts a positive relationship between monetary growth and inflation. Both, estimating the long term correlation of money and prices without risking the results to be driven by the common underlying trend, and estimating the short term impact of money growth on inflation, have been among the mostly analyzed empirical problems of the last decades. Evidence from cross country studies strongly supports the one to one correlation of average money growth and average inflation that can be derived from the quantity theory, as noted by McCandless & Weber (1995) among others. Lütkepohl & Wolters (2003) and Holtemöller

(2004) find evidence for a long run relationship in a VEC approach where money and prices are considered to be $I(2)$ or $I(1)$ after a nominal to real transformation. Nevertheless, the impact of money on prices is very hard to identify within one country. DeGrauwe & Polan (2001) have argued that the long run link between nominal money growth and inflation in countries which have operated in moderate inflation environments may be much looser than commonly assumed. Hence, the transmission process from money to prices seems to be strongly volatile. Furthermore, most studies are not conclusive about the appropriate horizon over which money is related to inflation, see for instance Shapiro & Watson (1988) and Christiano et al. (1999). Altogether, evidence whether present or lagged rates of money growth affect inflation is mixed at best. Since the immediate impact of money growth on inflation strongly varies, an error correction approach that accounts for the total monetary growth that has not become inflation yet seems to be appropriate.

However, even if inflation truly was 'always and everywhere a monetary phenomenon' in the long run, as stated by Friedman in his seminal 1963 book, a conventional vector cointegration approach does not necessarily identify the long run relation between money and prices correctly, due to the institutional changes that drive money velocity. In our paper we try to investigate the behavior of velocity in more detail, to capture more information that might be relevant for the determination of future inflation. Generally, there has been increasing interest in the behavior of veleocity recently. Benk, Gillman & Kejak (2009) for instance, embed money velocity in a DSGE model that is calibrated to US data.

Our model works with unadjusted money velocity and thus is similar to the setup used for example by Dreger & Wolters (2009) who impose a long run income elasticity of money demand of one.[4]. That is, we assume that velocity, albeit following a trend, is not driven by income in the short run. This differs from other recent approaches e.g. by Herwartz & Reimers (2006).[5] Albeit this assumption imposes a short run elasticity of money demand on income of one on the model, it does not impose this restriction in the long run. Persistent changes of any potential driving force of velocity are by construction attributed to our persistent velocity component. This holds not only true for the income as determinant of velocity,

[4] This assumption is not uncontroversial, but has been confirmed for some countries. See Wolters, Teräsvirta & Lütkepohl (1998) for the case of Germany.

[5] However, the decomposition we perform should identify the correct structural component of velocity independent of its causes.

but also for institutional change as financial innovation, wealth and other factors that are discussed in the correpsonding literature. This high flexibility of our model allows a parsimonious specification in terms of further controls. Anyhow, we test the income elasticity of money demand explicitly in our robustness section.

If a long term equilibrium of money velocity exists, our model implies that monetary growth beyond the (trend) GDP growth causes inflation. Contrarily to the bulk of the money demand literature, we explicitly test for this implication. That is, albeit assuming the long run relation of money, prices and output is given, we do not treat $m - p$ or $m - p - y$ as a single endogenous variable, but instead regress inflation, output growth and money growth on the theoretically derived error correction term separately. Essentially, we do not only test, whether money velocity $v_t$ exhibits a tendency to return to a long run equilibrium velocity $v_t^*$ or not, but also through which channels this adjustment occurs.[6] To do so it is necessary to decompose velocity into a persistent component, i.e. the long term equilibrium velocity, and a transitory component, i.e. the money overhang. First approaches that try to distinguish between equilibrium and current velocity show substantial improvements in the identification of the impact of money on prices. Orphanides & Porter (2000, 2001) use the difference between velocity and the predicted velocity of a simple regression model that explains movements in velocity with the opportunity costs of holding money as an indicator for monetary pressure in their version of the P*-framework. Instead of using just a simple univariate regression to explain movements in money velocity we adopt a multivariate unobserved components decomposition of velocity, that allows the identification of the long run equilibrium velocity while applying less restrictive assumption on specific driving forces of velocity.[7] Research

[6] Since the deviation of velocity from its long run equilibrium is mostly a short term adaptation to monetary policy, we refer to this deviation as 'money overhang' in the remainder of this paper, roughly following Gerlach & Svensson (2003).

[7] This is very important for our setup: As indicated above, contrarily to the P-star-approach that Orphanides & Porter use, we want to test through which channels the adjustment of velocity to its equilibrium happens. However, since the deviation of velocity from equilibrium is defined to be the part of velocity that is explained by the deviation of the opportunity costs of holding money from their equilibrium by Orphanides & Porter, the channel of adjustment is predefined in their approach. As these opportunity costs are mostly caused by central bank policy, money growth would be favored as channel of adjustment by construction. Thus, we choose an approach where we merely have to assume that an equilibrium exists, where deviations can be eroded by the growth of money, prices or production. Anyhow, we do find that monetary policy does indeed drive a large share of adjustment. Hence, our results are more or less in line with Orphanides & Porter as discussed in detail in the results section.

in a similar direction has been done by Bruggeman et al. (2005) who apply some frequency filtering techniques to velocity.

## 3 Dataset

To investigate our research question we analyze quarterly data from the United States. Our sample covers the period from 1959Q1 until 2007Q4. While data until 2009Q3 is available, we want to exclude the current crisis, since strong movements at the end of a sample, as they were recently observed in the development of GDP and the monetary aggregates, are known to strongly distort the filtering techniques we use. The vector of interest is $x = [m, p, y]$. In our preferred specifications the price indicator $p$ chosen is the consumer price index (CPI). As alternate measures we use core inflation, i.e. CPI excluding certain items that face volatile price movements, notably food and energy, and the implicit price deflator in the robustness tests. The monetary aggragate $m$ used in the baseline specification is M2. However, we also test our econometric models using alternate specifications based on more narrow definitions of money, M0 and M1. Production $y$ is defined as GDP throughout the paper, but monetary overhang is partially defined based on trend GDP as discussed in detail in the following section. The individual series have been tested to be difference stationary, at least at a ten percent significance level.[8]
Furthermore, we use specifications including the unemployment rate and the interest rate, more specifically the average federal funds rate. All data series are seasonally adjusted. Graphs of all time series used in the basic setup are found in the appendix (see Figure 4).

## 4 Model and Methodology

**Basic specification** The starting point for our analysis is the quantity theory:

$$m_t + v_t = y_t + p_t, \tag{1}$$

where $m$, $p$, $y$ and $v$ are the natural logarithms of money, prices, output and velocity and $t$ is a time index.

[8] Thereby, we used augmented Dickey-Fuller, Phillips-Perron, and KPSS tests.

We assume that

$$v_t = \tilde{v}_t + v_t^*, \tag{2}$$

$\tilde{v}_t$ being the transitory component of velocity. Analogously, $v*_t$ is the persistent component of velocity. We interpret the inverse of the transitory component as monetary overhang or excess liquidity.
The corresponding error correction style model we estimate thus takes the form:

$$\tilde{v}_t = -(m_t - p_t - y_t) - v_t^* \tag{3}$$

$$\begin{bmatrix} \Delta m \\ \Delta p \\ \Delta y \end{bmatrix}_t = A_1 * (-\tilde{v}_{t-1}) + A_2(L) \begin{bmatrix} \Delta m \\ \Delta p \\ \Delta y \end{bmatrix}_t + u_t,$$

where $A_i$ are coefficient matrices and $u_t$ is a vector of i.i.d. error terms. For reasons of simplicity of reading we will refer to the vector $[m, p, y]_t'$ as $x_t$ in the remainder of the paper.
We use $-\tilde{v}_{t-1}$ instead of $\tilde{v}_{t-1}$ in the adjustment equations, so the reported adjustment coefficients can be readily interpreted as the consequence of lagged money overhang.

**Business cycle neutral specification** A shock to output $y_t$ is mirror by a corresponding change in the velocity of money. Since output commonly returns to its potential with analogue impact on velocity, a shock that causes a deviation from potential output will most likely be attributed to the cyclical component of velocity. By construction this return of velocity to its equilibirum is accompanied by the return of output to its potential. This might erroneously be read as a positive growth effect of excess liquidity, even though there is no causality between excess liquidity and growth.
To disentangle the error correction that is due to the tendency of $y$ to return to potential output and error correction that happens due to a positive growth impact of liquidity, we use an alternative specification of money overhang. The corresponding defition of business cycle neutral velocity is given by:

$$v_t^{BCN} = -(m_t - p_t - y_t^*) - v_t^*, \tag{4}$$

where $y^*$ is trend logged GDP (derived using the Hodrick-Prescott filter). This results in a specification that is quite close to the P-Star-model proposed by Gerlach & Svensson (2003).

Both, the business cycle adjusted model and the unadjusted model, are estimated using different estimates of $\tilde{v}_t$ that are briefly outlined in the following subsections.

## 4.1 Conventionally detrended velocity

**Linear trend** As a baseline specification we employ a conventional VECM with known cointegration vector and a linear trend in the cointegration relation. Thus, the long term relationship of money and prices given in equation (3) is specified more precisely by:

$$\tilde{v}_t = -(m_t - p_t - y_t) - \underbrace{\alpha_0 + \alpha_1 t}_{v_t^*}. \qquad (5)$$

**HP-filtering of velocity** While it seems reasonable to assume that technical progress that drives the institutional component of velocity is strictly monotonous, it is not necessarily linear. Since innovation is not known ex ante, it is hard to predict technical progress more precisely than a linear forecast. However, ex post we can identify whether a change of velocity has been permanent or transitory. If a concept like a long term equilibrium of velocity truly exists, this would equal the persistent component of velocity by definition. As a first attempt to disentangle persistent and transitory movements, we employ the filter of Hodrick and Prescott, taking the HP-trend as the long term equilibrium velocity. While this does not necessarily help to improve forecast of velocity, it increases the quality of the parameter estimates substantially, by avoiding a possible bias due to the misspecification of velocity. The following section includes some more sophisticated filtering techniques. However, the HP-based model represents a natural first approach, due to its widespread use and the resulting high degree of comparability. The HP-filter estimates are used as starting values for these decompositions. The big advantage of the HP-filter is that it strongly enforces a stationary cyclical component, and thus allows a computationally efficient search of an decomposition that fulfills this criterion.

## 4.2 Unobserved components decompositions of velocity

**Univariate unobserved components decomposition of velocity** In a further attempt to identify the structural component we use a state space model to estimate the unobserved components:

$$v_t = \tilde{v}_t + v_t^* \tag{6}$$

$$v_t^* = v_{t-1}^* + \alpha_1 + \varepsilon_{1t}$$

$$\tilde{v}_t = \phi(L) * \tilde{v}_t + \varepsilon_{2t}.$$

Thus, we decompose velocity into a random walk with drift as a trend component and an autoregressive $I(0)$ process. By that, we impose quite strong restrictions on money overhang, which is reverting to a zero mean by construction. Therefore, this procedure is inappropriate to test whether velocity is mean reverting or not. However, it allows to focus on the question through which channels the reversion of velocity to its long run equilibrium occurs, conditional on the assumption that a long run equilibrium exists. This state space representation where the evolution of the signal variable $v_t$ is explained by the (unobserved) states $\tilde{v}_t$ and $v_t^*$ is estimated using the Kalman-Filter.[9] For a given initial state and given coefficient matrices the Kalman filter provides recursive estimates for the state in period $t$ and its variance using the newly arrived information of the signal variable and the lagged estimated states. The coefficient matrices are then estimated with standard MLE by numerically optimizing the likelihood that can be derived from the prediction error decomposition of the Kalman-Filter.

The unobserved components approach we use is very similar to the more frequently applied Beveridge-Nelson-decomposition. However, we chose to employ the univariate unobserved component decomposition, since it is closer to our full multivariate model that is described in the following section.

**Multivariate unobserved component decomposition** Following Gerlach & Smets (1999) who embed the unobserved components decomposition of GDP into a

[9] A detailed survey regarding state space methods can be found in Durbin & Koopman (2001) and Harvey (2006).

multi-equation system that takes a New Keynesian Phillips Curve into account, we include the state space decomposition of the previous paragraph into our original equation system of interest. The full state space model then takes the form:

$$\Delta x_t = A_1 * (-\tilde{v}_{t-1}) + A_2(L)x_t + u_t \tag{7}$$
$$v_t = \tilde{v}_t + v_t^*$$

$$v_t^* = v_{t-1}^* + \alpha_1 + \varepsilon_{1t}$$
$$\tilde{v}_t = \phi(L) * \tilde{v}_t + \varepsilon_{2t}.$$

This does not only lead to improved estimates of the unobservable components but also improves the quality of the parameter estimates in the core equation system that explains the vector $x_t$. Given the three lags we use in the preferred model setup, the estimation requires the simultaneous determination of 42 parameters by numerical optimization of the likelihood function. Owing to the resulting complexity of the likelihood function we use different optimization procedures to rule out possible local maxima. Therefore, we used a slightly adapted version of the genetic optimization algorithm developed by El-Shagi (2010), and the simplex routine provided by the Matlab optimization toolbox. Both routines produce similar results. The ones presented here are based on the Matlab routine.

# 5 Results

## 5.1 Estimates of transitory velocity

Figure 1 provides a visual inspection of the transitory components of velocity that are derived using the approaches outlined above. Figure 5 in the appendix additionally depicts the trend component of the multivariate model.

The Hodrick-Prescott-Filter leads to a strongly cyclical estimation of transitory velocity by construction. While the huge difference to the linear trend estimation nicely highlights the possible importance of distinguishing transitory and persistent components, the structure that is enforced on the cycle seems too rigid to allow for a plausible explanation of inflation.

Thus we focus on the unobserved components decomposition of velocity that is performed through the Kalman Filter. Both the univariate and the multivariate model of the transitory velocity, i.e. of money overhang, produce similar estimates of its general evolution. However, the results differ clearly at the end of sample. For the estimation of the consequences of the recent monetary policy in response to the financial crisis it is essential to be able to identify the original level of money overhang.

While the univariate approach indicates that velocity is close to its long term equilibrium, there is a substantial money overhang according to the multivariate model. Looking at the monetary policy of the federal reserve since the collapse of the dotcom-bubble in 2001 the latter estimation seems more plausible.

The estimation derived by the univariate model is strongly driven by the assumptions. Without the additional information that is exploited in the multivariate model, the mean reversion of transitory velocity that is enforced on the estimate, does not allow for lasting disequilibria. Contrarily, while also assuming mean reversion of transitory velocity in general, the identification of actual mean reversion in a given period is based on joint evidence from inflation, money growth and GDP growth in the multivariate model. Sustained disequilibria that are caused by lasting periods of unusual monetary policy, as seen in the first decade of the present century, can thus be correctly identified by this approach.

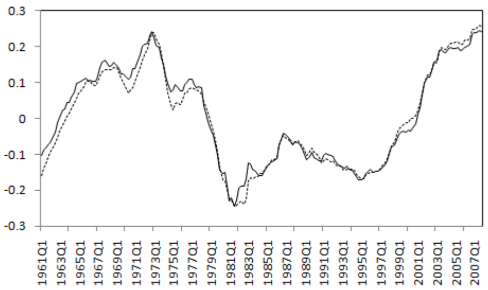
Given the importance of knowing the original level of money overhang before the crisis and the corresponding monetary reaction, we strongly suggest using the multivariate approach, that estimates a level of money overhang in 2007 that has not been seen since the stagflation period in the 1970s.

## 5.2 Estimates of the adjustment process

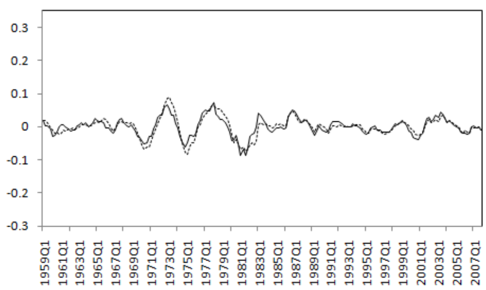
All our models show a clear and significant positive impact of money overhang on inflation. The coefficient estimates range from roughly 0.006 in the baseline estimation via 0.017 if the univariate unobserved components model of velocity is used to 0.07 if the HP-filtered trend of velocity is removed. A large part of the variation in the coefficient estimates is due to differences in estimated magitude of the transitory component of velocity. The change of quarterly inflation (in annualized rates) if the money overhang changes by one standard deviation is about 0.5 percentage points.

Figure 1: Transitory velocity component

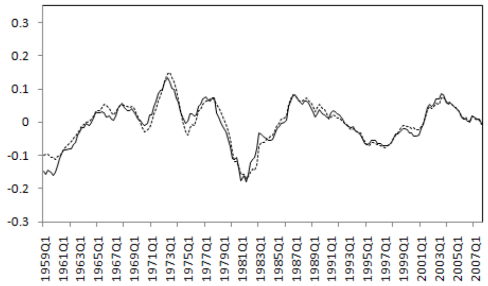
(a) Linearily detrended velocity



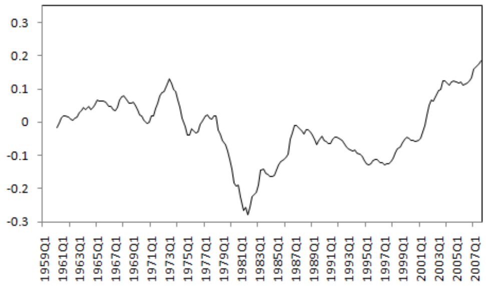

(b) HP detrended velocity




(c) Univariate kalman filter detrended velocity




(d) Multivariate kalman filter detrended velocity




*Notes*: The solid lines represent the basic estimates, the dotted lines represent the business cycle neutral estimates.

In the baseline estimation where the institutional component of velocity is modeled as a linear trend, we find a positive impact of money overhang on GDP growth as well. However this effect disappears, if we employ $v^{BCN}$ as velocity indicator. Thus, as expected, the results indicate no causality from excess liquidity to production, but only reflect the tendency of GDP to return to its potential. This is in line with the result based on the unobserved components decompositions, where the correlation between $v_t^*$ and growth is very weak, since the GDP cycle seems to be attributed to the trend component.

The results concerning the behavior of the central bank in response to monetary overhang are mixed. While the federal reserve seems unobservant of money overhang according to the baseline estimation, the other models indicate a strong reaction of monetary policy (in terms of the growth rate of M2). Since the linear approximation of the institutional component of velocity is a strong simplification, the latter results probably catch the true behavior of the federal reserve more precisely. Furthermore, the impact of inflation on money growth is insignificant. This might be read as an indicator that the Fed, while taking monetary pressure into account, does not resort to strong discretionary reaction in response to current inflationary tendencies. However, the results including interest rates that are presented in detail in the robustness section contradict this interpretation. The reported results use three lags, as indicated by the AIC and the Hannan-Quinn-Criterion. For reasons of comparability the autoregressive order of the transitory component of velocity is also assumed to be three in the corresponding state space approaches.

Table 1: Error Correction Estimates

| Trend Specification | Error Correction | | |
|---|---|---|---|
| | $\Delta$ CPI | $\Delta$ M | $\Delta$ GDP |
| Business cycle neutral | | | |
| Linear trend | 0.006771 | -0.006078 | -0.003057 |
| | (3.20491) | (-1.59077) | (-0.72914) |
| HP-filtered trend | 0.078366 | -0.1355 | 0.04577 |
| | (7.91131) | (-7.70098) | (2.02033) |
| Kalman filtered trend - univariate | 0.021412 | -0.033312 | 0.006462 |
| | (4.73524) | (-4.11920) | (0.67704) |
| Not business cycle neutral | | | |
| Linear trend | 0.006046 | -0.004362 | 0.000069 |
| | (2.85297) | (-1.14529) | (0.01529) |
| HP-filtered trend | 0.070082 | -0.115226 | 0.104126 |
| | (6.28376) | (5.77365) | (4.47131) |
| Kalman filtered trend - univariate | 0.017638 | -0.026146 | 0.013801 |
| | (3.92283) | (-3.25565) | (1.48719) |
| Kalman filtered trend - multivariate | 0.0106 | -0.0118 | 0.0006 |
| | (3.4329) | (-2.1131) | (0.1025) |

*Notes:* t-values are given in parentheses.

In the multivariate approach stationarity is enforced on the transitory component of velocity. However, we interestingly find that the first component of the autoregression vector is larger than one. This is presumably driven by the strong autoregressive process of inflation and money growth. While strong deviations from the long run equilibrium cannot be sustained for too long, the momentum in the dynamics of money and inflation can cause extended periods of growing deviation until the monetary pressure finally overtakes. All filtering mechanisms (including the simple HP-filter) find evidence for an increased speed in the development of equilibrium velocity in the middle of the sample. This roughly corresponds to the results of Orphanides & Porter (2001).

To summarize, we clearly find that the return of velocity to its long run equilibrium is mostly driven by inflation. Due to the caveat that we partially enforce stationarity of money overhang, this does not necessarily prove that inflation is driven by money supply. However, the results strongly support this hypothesis and show that the data is absolutely in line with the assumption that money drives inflation. The key results are summarized in table 1. The table includes the adjustment coefficients, i.e. the vector $A_1$, and the corresponding t-statistics for the specifications outlined above.

None of the three error series estimated exhibits autocorrelation (in the first 8 lags, see table 3 in the appendix for details).

While the residuals are not normally distributed according to a Jarque-Bera-test, this is mostly due to excess kurtosis and not due to skewness that is close to zero. It has been shown in simulation studies that the VAR approach, that is sensitive to skewness violating the underlying assumptions, is quite robust to excess kurtosis[10]. Thus, the kind of nonnormality we find does not affect our results substantially.

# 6 Robustness and Extensions

To strengthen our arguments we impose several robustness tests that generally brace the validity of our results.

## 6.1 Different variables and sample sizes

In a first step we adjust the sample to test whether there are different time regimes. We estimated the models for the full pre-financial crisis sample, for the post Bretton

[10] see Bai & Ng (2005) and references therein.

Woods period, and the period after stagflation.[11] Independently from these sample specifications, we always find a significant effect of money overhang on inflation.

As a further robustness check we incorporated different money, price, and output series, i.e. M0, M1, M2 for money; CPI, core CPI, and the implicit price deflator for prices; GDP, and potential GDP for output.

Both, the impact of money overhang on inflation and the impact of money overhang on the growth of the money stock itself are quite robust. As can be seen in table 4 in the appendix, all specifications using M2 and the clear majority of specifications using M0 and M1 we find an impact of money overhang on inflation of roughly the same magnitude. Generally, the significances of the adjustment process through inflation are lower in the business cycle neutral specification.

## 6.2 Possibly omitted variables

Recent contributions argued that the impact of money on prices that is found in some studies is mostly due to omitted variables, most notably unemployment and interest rates. Therefore, as a further robustness check we expand our vector autoregressive model accounting for these allegedly omitted variables. For simplicity these extensive tests are based on the equilibrium long run velocity that is estimated using the univarite Kalman filter, that demands substantially less computational resources. The results on the impact of money overhang on inflation remain essentially unchanged if unemployment rate or interest rates, measured as the average U.S. federal funds rate[12] are included. However, the regression yield some interesting new results, see table 5.

Unemployment is significantly decreased by excess money, indicating a kind of Phillips-curve-effect. Nevertheless, lagged inflation itself is surprisingly positively correlated with unemployment. Albeit, the latter result is mostly driven by the stagflation period. If the sample is restricted accordingly to the period after 1984 the correlation disappears.[13]

[11] The velocity decompositions are always based on the full sample. Thus, this does not work using the multivariate Kalman Filter.

[12] Since interest rates are instationary according to an augmented Dickey-Fuller test, we use the first difference instead.

[13] This does not necessarily imply that long lasting periods of inflation do not contribute to unemployment; but due to the generally low rates of inflation in the U.S. after the oil crisis these problematic levels possibly have not been reached.

Interest rates are strongly positively affected by lagged inflation. Contrary to the preliminary evidence from money growth, that responds quite slow to policy itself, this indicates rather strong and quick discretionary responses on deviation from the targeted inflation rate. Unsurprisingly, interest rates also increase significantly if the monetary overhang is high. It is quite notable that the correlation of lagged inflation and interest rates disappears if the sample is restricted to the Greenspan area. This fits the general picture of Greenspan, who was not known for excessive fear of inflationary tendencies.

## 6.3 Regime stability in a time varying adjustment setup

As a final check several stability tests are performed to emphasize the time invariance of our model. Since the empirical relevance of the quantity equation has often been criticized and the relevant processes might admittedly be prone to changes in the political framework, we do not only rely on standard approaches to test the parameter stability hypothesis, but include our model in some general setups, that account for a number of possible nonlinearities.

To get a first impression of parameter stability, we run the standard CUSUM and CUSUM of squares tests. These tests can be applied to the individual equations of our vector model. If the cumulative sum of recursive residuals wanders off to far from the zero line, it signals evidence against structural stability. There is no evidence for a structural break in the parameter regime.[14] However, the CUSUM type tests have only limited power in general and are furthermore mostly appropriate to test for permanent changes in the regime. Thus, they do not necessarily detect changes over time if these changes are transitory, as in regime changing approaches.

To capture such possible non permanent changes of the adjustment coefficients we embed our model in a state space representation where the adjustment coefficients are treated as unobserved states. The model thus can be written:

$$v*_t = -(m_t - p_t - y_t) - \tilde{v}_t \tag{8}$$

$$x_t = A_{1,t} * (-\tilde{v}_{t-1}) + A_2(L)x_t + u_t,$$

[14] The dotted lines refer to the confidence bounds at 1 percent significance.

$$A_{1,t} = A_{1,t-1} + \varepsilon_{At},$$

This specification equals our original specification with the only difference that $A_1$ is treated as a time variant state that behaves like a random walk and thus has to be denoted $A_{1,t}$.[15] As it can be seen in the model, this approach is designed to capture a random walk like behavior of the state variables of interest. However, since the model allows this huge freedom to possible changes in $A_1$ it should be able to capture at least some of the movement that might be generated by other kinds of regime changing, like Markov-Switching or threshold effects. This flexibility is our main reason, to focus on this analysis as a parameter stability test.

The smoothed state estimates for the $A_1$ show that the reaction of inflation and money growth to money overhang is clearly constant. There is a very small change in the estimate concerning the adjustment coefficient. However, the coefficient is insignificant anyhow, as found in the constant parameter regime estimates.

Thus we can conclude, that the impact of money on prices is highly stable.

## 6.4 An alternate view on the dynamics of persistent velocity

The s-shaped form of the persistent component of money velocity we estimate, suggests that there is not only persistence in some developments of velocity itself but in the speed of its changes. There are several factors that might contribute to these developments: Periods of intensive financial innovation, enduring developments of production or wealth and other potential driving forces of long run velocity might play a role in the pattern we observe. To avoid possible problems that might arise from the autocorrelation in the errors of the persistent velocity series $\varepsilon_1$ that is implied by these findings, we estimate an alternative setup that allows for persistent changes in the drift component of $v^*$.

$$\Delta x_t = A_1 * (-\tilde{v}_{t-1}) + A_2(L)x_t + u_t \tag{9}$$

$$v_t = \tilde{v}_t + v_t^*$$

[15] Since the Kalman-filter based MLE that is used to estimate the model cannot handle unobserved states that impact the signal variables with time varying coefficients, these tests cannot be performed for the multivariate velocity filtering approach.

$$v_t^* = v_{t-1}^* + \mu_t + \varepsilon_{1t}$$

$$\tilde{v}_t = \phi(L)\tilde{v}_t + \varepsilon_{2t}$$

$$\mu_t = \mu_{t-1} + \varepsilon_{3t}$$

The results concerning the impact of money on inflation (see table 2) are very close to the results obtained using our original multivariate state space model.

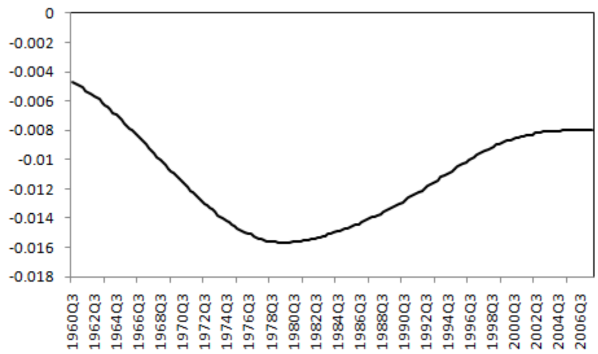
Table 2: Time varying drift

| Specification | Error Correction | | |
|---|---|---|---|
| | Δ CPI | Δ M | Δ GDP |
| Time varying drift | -0.011556<br>(-1.771439) | 0.011799<br>(3.267415) | 0.005266<br>(0.742329) |

*Notes:* t-values are given in parentheses.

The drift $\mu$ is fairly close to zero in the beginning of the sample but increases strongly (in absolute terms) in the following decades. After peaking around the oil crisis the speed of the velocity development declined again. However, the drift has been quite constant in the past decade (see Figure 2).

Figure 2: Time varying drift



### 6.5 Estimating the income elasticity of money demand

Since the impact of income on velocity is mostly of long run nature, it should correspondingly be captured by our persistent velocity component. However, to make sure that a potential stable short run correlation of income and velocity, that cannot be ruled out definitely, does not distort our results, we test a battery of models where income elasticity of money demand is explicitly modeled.
Essentially this is done by replacing money velocity with an adjusted velocity that is given by:

$$v_t^{adj} = m_t - p_t - \gamma * y_t. \qquad (10)$$

This alternative setup is then estimated in our multivariate approach for a range of $\gamma$s between 0.5 and 1.5, that covers most values for the income elasticity of money that are found in the previous empirical literature or derived in the respective theoretical papers (Knell & Stix 2005).
Both, the Kalman-Likelihood and the Gaussian-Likelihood calculated based on the total fit of the model, are quite flat in this setup. Furthermore, our key results on the cyclical component of velocity and its impact on inflation remain almost unchanged by these augmentations of the original multivariate model.

## 7 Consequences of the monetary reaction on the financial crisis

Our model allows forecasts that are based on different policies. Since the recent monetary policy creates a substantial challenge for future monetary policy, this is of major interest.

### 7.1 The baseline forecast

Our baseline forecast is derived straightly from our multivariate Kalman-Filter estimation. Since $\Delta m$ is determined endogeneously, this includes the implicit assumption that the exit strategy of the Federal Reserve mirrors the previous policy for the reduction of excess liquidity. Although this implies an annual cutback in M2 that has not been seen in the past 30 years, the model predicts an inflationary wave with annual inflation rates above the 6% threshold for 5 years, peaking at almost 10% inflation rates.

The quite broad confidence bands that can be seen in Figure 6 (appendix) are mostly due to high degree of uncertainty in output growth that subsequently causes high uncertainty in future inflation that depends on growth.

## 7.2 Alternate policy scenarios

Due to the monetary policy in response to the crisis excess liquidity and the corresponding inflationary pressure reached a magnitude that is unique in post stagflation period. Thus, the behavior of central banks that could be observed in the past possibly is no valid estimate for the exit strategy of the Federal Reserve.

We simulate our model with two alternative approaches that combat excess liquidity more drastically.

Our model does not include an explicit policy instrument as interest rates. Assuming for simplicity that the central bank can roughly control money supply, we thus employ $\Delta m$ as a substitute policy variable. Since the key issue, we want to tackle with our forecast, is the size of a possible inflationary wave rather than its precise timing, a possible lag between monetary policy actions and money growth is of limited importance. Thus, this simplicifation is feasible, if the central bank can control M2 growth in the medium run.

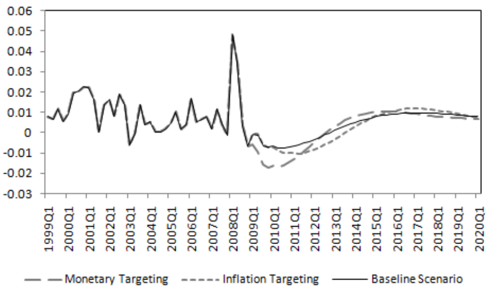
First, we substitute the original regression coefficient of inflation in the money growth equation by an alternative value of twice the size. The constant in the money growth equation is correspondingly adjusted to maintain the original steady state inflation rate. Thus, this scenario loosely corresponds to inflation targeting, assuming that the inflation target has been hit on average in the past.

Secondly, we substitute the regression parameter of money overhang in the money growth equation by an alternative value of twice its size. Again, the constant is adjusted to maintain a stable steady state. This roughly corresponds to the idea of monetary targeting if we assume that the central bank aims to correct for past 'mistakes'.

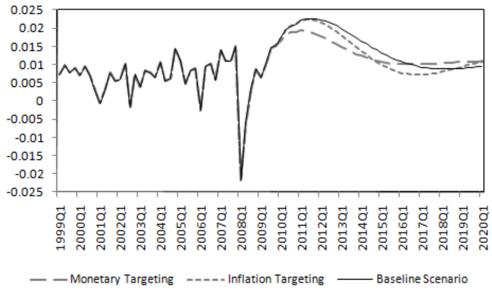
Figure 3 shows the 40 period ahead forecasts from the baseline model, the monetary targeting and inflation targeting scenarios. Albeit knowing that a 40 period ahead forecast has to be taken with caution, we want to present the full dynamics of the system until the relevant part of the response to the policy shock has died out.

Figure 3: Policy simulation

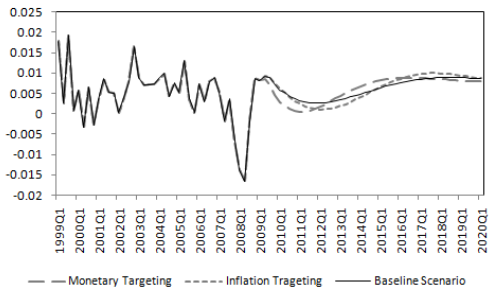
(a) Money Growth Simulation




(b) Inflation Simulation




(c) Output Simulation




All three models indicate a clear and to some extent dramatical reaction of inflation and output. However, the model only captures the growth component that is due to inflation or money overhang that might impede growth in the coming years. The closing of the output gap, that quite likely will be the driving force behind growth in the near future is not considered.

Both exit strategies analyzed shorten high inflation period. Nevertheless, only the version of monetary targeting (that more precisely is an excess liquidity targeting) reduces the peak level of future inflation.

While the inflation targeting quickly reduces inflation, there is strong overshooting below the steady state level. This can partly be explained by the central bank looking at past inflation instead of expected inflation in our simplified model.

Albeit monetary targeting performs very well in terms of price stability, its growth performance is the worst among the cases we analyze. Inflation targeting produces results that are only marginally better. Although total growth possibly will be substantially higher due to the closing output gap, these results emphasize the substantial costs that are associated with the exit strategies that are necessary to avoid high inflation.

# 8 Conclusion

Altogether we find clear evidence that inflation is heavily influenced by money overhang, once velocity is appropriately taken care of in the underlying definition of money overhang. The changes in the growth rate of long run equilibrium velocity seem to be one of the major problems of previous attempts to analyze the role of money for inflation. These results could only be achieved by including velocity in a structural model that nevertheless does not impose any restrictions on possible driving forces of velocity. However, one caveat of our approach is that the (rarely doubted) existence of a long run equilibrium of velocity has to be exogenously imposed on the econometric model. Conditional on this existence we can strongly support the thesis of inflation as a monetary phenomenon.

We also find new evidence that monetary policy is not only driven by recent developments of macroeconomic indicators, but accounts for previous monetary policy that has not yet had its expected inflationary effect.

Our forecasts suggest, that no exit strategy can prevent inflation without substantial growth losses.

To avoid high inflation or the problems that might arise if excess liquidity is reduced by negative money growth, it seems most feasible to stabilize the current level of velocity, i.e. to deliberately render the transitory change in velocity persistent. A substantial part of the current velocity can most likely be explained by the increased risk aversion of banks in response to the current crisis and the corresponding deleveraging. Since the risk preference of banks in the pre crisis period is widely considered as too high, a banking regulation that prevents the banks to return to their old behavior might not only prevent inflationary pressure but also reduce the systemic risk of the financial sector.

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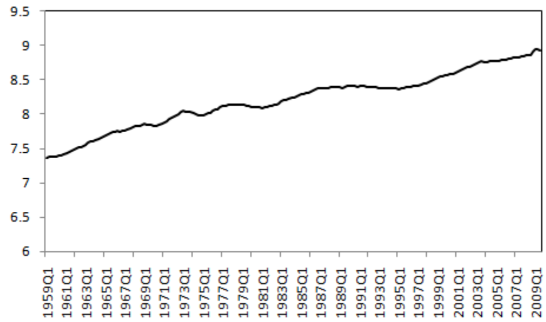
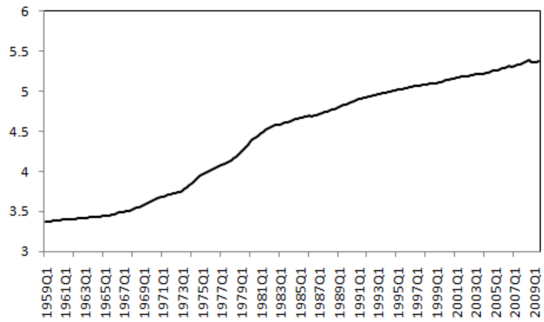
# A Graphics and Tables

Figure 4: Logged data series

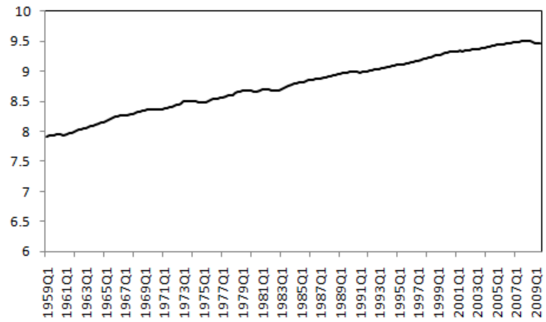
(a) Monetary aggragate M2




(b) Consumer Price Index




(c) Gross Domestic Product




(d) Money Velocity

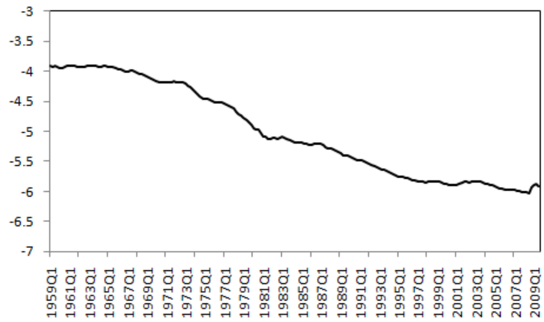



Figure 5: Estimated trend - Multivariate unobserved components model

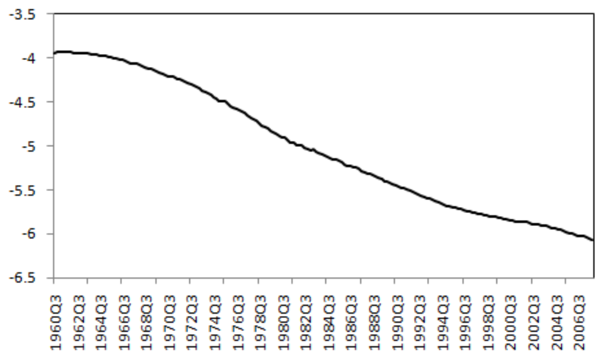


Figure 6: Inflationary reaction with 80 percent confidence bounds

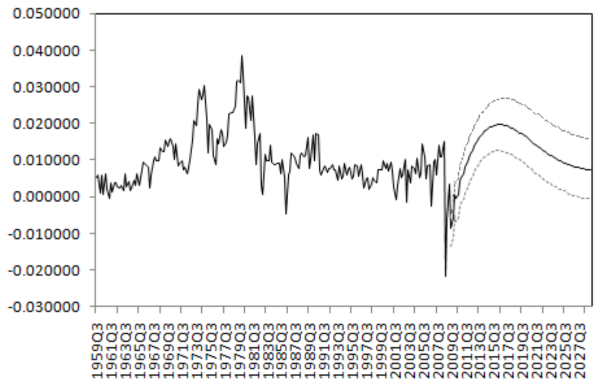


Table 3: Test for the Autocorrelation of Residuals in the difference equations

| Lags | Residual Series | | |
|---|---|---|---|
| | $u_1$ | $u_2$ | $u_3$ |
| 1 | 0.416 | 0.664 | 0.980 |
| 2 | 0.654 | 0.881 | 0.992 |
| 3 | 0.770 | 0.968 | 0.994 |
| 4 | 0.284 | 0.692 | 0.976 |
| 5 | 0.335 | 0.79 | 0.934 |
| 6 | 0.439 | 0.759 | 0.969 |
| 7 | 0.309 | 0.822 | 0.847 |
| 8 | 0.158 | 0.144 | 0.628 |

*Notes:* The listed values are p-values of the Ljung-Box-test for autocorrelation.

Table 4: Robustness Check - Different Variables

| Monetary Aggregate | Prices | BCN | Δ P | | Δ M | | Δ Y | |
|---|---|---|---|---|---|---|---|---|
| m0 | cpi | X | 0.021014 | (2.177940) | -0.030328 | (-1.992877) | 0.051207 | (2.577875) |
| m0 | cpi | | 0.035463 | (3.882960) | -0.035302 | (-2.396661) | 0.008730 | (0.444063) |
| m0 | core | X | 0.013875 | (1.572340) | -0.037421 | (-2.325350) | 0.049536 | (2.413036) |
| m0 | core | | 0.029101 | (3.394289) | -0.039154 | (-2.448468) | 0.004366 | (0.210380) |
| m0 | defl | X | 0.011991 | (1.531116) | -0.043780 | (-2.490511) | 0.059325 | (2.510884) |
| m0 | defl | | 0.025701 | (3.356665) | -0.050891 | (-2.908917) | -0.014038 | (-0.58388) |
| m1 | cpi | X | 0.010476 | (2.059724) | -0.034218 | (-3.195680) | 0.016283 | (1.566476) |
| m1 | cpi | | 0.015683 | (3.060799) | -0.037747 | (-3.468307) | 0.006110 | (0.572223) |
| m1 | core | X | 0.006780 | (1.478762) | -0.036267 | (-3.204024) | 0.013860 | (1.278793) |
| m1 | core | | 0.011523 | (2.486928) | -0.041408 | (-3.606510) | 0.002495 | (0.224390) |
| m1 | defl | X | 0.003260 | (0.827746) | -0.040213 | (-3.398035) | 0.017423 | (1.501100) |
| m1 | defl | | 0.007217 | (1.770345) | -0.047248 | (-3.864509) | 0.001463 | (0.120239) |
| m2 | cpi | X | 0.017638 | (3.922828) | -0.026146 | (-3.255649) | 0.013801 | (1.487188) |
| m2 | cpi | | 0.021412 | (4.735245) | -0.033312 | (-4.119200) | 0.006462 | (0.677043) |
| m2 | core | X | 0.013098 | (3.201270) | -0.028812 | (-3.389569) | 0.014326 | (1.506115) |
| m2 | core | | 0.016231 | (3.815746) | -0.037703 | (-4.294528) | 0.006989 | (0.695448) |
| m2 | defl | X | 0.011743 | (3.255334) | -0.028427 | (-3.066641) | 0.010682 | (1.009657) |
| m2 | defl | | 0.014437 | (3.964666) | -0.037280 | (-3.999116) | -0.000486 | (-0.04479) |

*Notes:* t-values are given in parentheses to the right of the coefficient estimates.

Table 5: Omitted Variables

| Trend Specification | Error Correction with u-rate | | | | Error Correction with interest rates | | | |
|---|---|---|---|---|---|---|---|---|
| | Δ CPI | Δ M | Δ GDP | u-rate | Δ CPI | Δ M | Δ GDP | interest rate |
| Business cycle neutral | | | | | | | | |
| Linear trend | 0.005314 | -0.002888 | 0.002294 | -0.26881 | 0.005005 | -0.003083 | -0.003745 | 1.049924 |
| | (2.14683) | (-0.65262) | (0.46647) | (-1.76017) | (2.42782) | (-0.80765) | (-0.90435) | (2.06197) |
| HP-filtered trend | 0.071053 | -0.121343 | 0.042314 | -2.269615 | 0.072254 | -0.126143 | 0.033 | 11.6089 |
| | -7.23235 | (-6.95126) | (1.87433) | (-3.26775) | (7.53539) | (-7.15772) | (1.47259) | (4.57698) |
| Kalman filtered trend - univariate | 0.017994 | -0.028605 | 0.012575 | -0.6979 | 0.020109 | -0.031161 | 0.002413 | 2.401800 |
| | (3.87717) | (-3.47204) | (1.28126) | (-2.28959) | (4.72045) | (3.96102) | (0.26089) | (2.21267) |
| Not business cycle neutral | | | | | | | | |
| Linear trend | 0.004395 | -0.000983 | 0.006269 | -0.291204 | 0.004538 | -0.001783 | -0.000522 | 0.867949 |
| | (1.83319) | (-0.23062) | (1.27544) | (-1.89925) | (2.22111) | (-0.47433) | (-0.12305) | (1.73560) |
| HP-filtered trend | 0.068238 | -0.107563 | 0.091042 | -3.039061 | 0.068681 | -0.11269 | 0.089223 | 10.49200 |
| | (6.32760) | (-5.53988) | (3.89509) | (-4.16882) | (6.51979) | (6.51979) | (6.51979) | (6.51979) |
| Kalman filtered trend - univariate | 0.014296 | -0.021085 | 0.017073 | -0.706946 | 0.017765 | -0.026234 | 0.009787 | 1.827122 |
| | (3.22237) | (-2.67505) | (1.85123) | (-2.46150) | (4.21441) | (-3.37049) | (1.08496) | (1.71136) |

*Notes:* t-values are given in parentheses.