Money Growth, Output Gaps and Inflation at Low and High Frequency: Spectral Estimates for Switzerland

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Abstract

While central banks generally have abandoned monetary targeting, many continue to attach weight to monetary aggregates in setting policy. This raises the issue of how money can be combined with other variables when analysing inflation. The Swiss National Bank (SNB) emphasises that the indicators it uses to do so vary across forecasting horizons. While real indicators are employed for short-run forecasts, money growth is more important at longer horizons. Interpreting statements about the long (short) run as referring to low (high) frequencies, we use spectral methods to show that the SNB's view of the inflation process fits the data well.

Keywords: spectral regression, frequency domain, Phillips curve, quantity theory.

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1. Introduction

Reflecting the increasingly common practice of gearing monetary policy directly to the goal of price stability, many if not all central banks in industrialised economies have abandoned monetary targeting. Nevertheless, most continue to attach some weight, large or small, to the monetary aggregates in setting interest rates. This raises the general issue of how central banks can best combine the information contained in the monetary aggregates with that in other variables, in particular measures of the cyclical state of the economy and cost-push shocks, in analysing and forecasting inflation.

The Swiss National Bank (SNB) is a case in point. At the beginning of 2000, the SNB modified its monetary policy framework, having since the early 1970s used several monetary targeting strategies to guide policy.[1] In the period 1990-1999, this approach entailed an objective for the seasonally-adjusted monetary base, which was expressed for the medium-term since money growth impacts on inflation at that time horizon.[2] However, since the target had been considered to be only a guideline and it since was felt that the information content of money had declined in the late 1990s, the decision was taken to adapt the framework by dropping the monetary target. This also enabled the SNB to clarify that policy had been and would continue to be conducted using a broad range of indicators rather than being narrowly restricted to information embedded in the monetary aggregates. Thus, in deemphasising the monetary target, the new strategy largely realigned words with deeds but did not fundamentally change the role of money in the SNB's conduct of policy.

The strategy has three new components: a definition of price stability as CPI inflation of less than 2 percent per year; the use of a forecast for inflation as the main indicator for guiding monetary policy; and an operational target for three-month Libor.[3] Under the new strategy, the Board of the SNB convenes quarterly to assess the stance of policy. Following the meetings, the SNB publishes an inflation forecast based on a scenario for the development of the global economy and the assumption that three-month Libor will remain constant over the

[1] See the statement of Meyer (1999), in which the new strategy was announced, and SNB (2005) for more information. Genberg and Kohli (1997), Peytrignet (1999) and Hildebrand (2004) review the evolution of the SNB's monetary policy framework, and the role of money in it, from 1973 to 2004. Rich (2003) also provides an overview of the monetary targeting experience.

[2] A further reason was that a medium-term target allowed the SNB to respond flexibly to other indicators, in particular the state of the business cycle. See Meyer (1999).

[3] While the objective of policy is to avoid persistent inflation above this rate, faster price increases may be tolerated temporarily since it is difficult for central banks in highly open economies to prevent exchange rate changes and external price shocks from exerting short-run effects on domestic prices.

three subsequent years, which corresponds to the time the SNB believes is required for policy actions to be fully transmitted to the economy.

Money plays no privileged role in the new framework. However, given the central importance of the inflation forecast, all variables that impact on the outlook for prices are incorporated in the policy analysis. Monetary aggregates receive considerable attention since they are seen as useful for predicting inflation, particularly towards the end of the forecasting horizon.[4] By contrast, in the medium term, attention is focussed on economic prospects and measures of the output gap. In the short term, factors such as the exchange rate, prices of raw materials including oil, administered prices and value-added tax rates are of significance.

To understand the role played by the monetary aggregates in the new monetary policy strategy, it is instructive to consider the views of Jordan et al. (2001, p. 48), who emphasise the importance of the time horizon in analysing inflation:[5]

> *"The SNB … continues to monitor two sets of indicators providing leading information on future price developments …. The first set of indicators is useful for forecasting short-run price developments …. It includes various indicators on the cyclical state of the economy, notably the output gap …as well as the real exchange rate of the Swiss franc. The second set of indicators comprises the monetary aggregates, which provide useful leading information on long-run price developments. […] Both sets of indicators are used together with the forecasts from various econometric models to produce a broadly based consensus inflation forecast, which now forms the centre stage of Swiss monetary policy."*

As this quote makes clear, the SNB's view of the inflation process is close to that which underlies the European Central Bank's (ECB) two-pillar strategy, which similarly distinguishes between the roles of monetary and economic factors and the time horizons at which they operate (ECB, 2003, Gerlach, 2004, and Assenmacher-Wesche and Gerlach, 2006, 2007). In the literature a number of authors have formalised the ECB's view of the determination of inflation using a Phillips curve augmented with a term capturing the low-frequency movements in the growth rate of M3.[6] In this model, the output gap is seen as capturing the economic conditions that are useful for forecasting inflation in the near-term, and the measure of trend money growth as reflecting inflation pressures in the more distant

[4] Methods to forecast inflation have been discussed extensively in the Quarterly Review of the SNB; see Jordan and Peytrignet (2001), Stalder (2001), Jordan et al. (2002), and Jordan and Savioz (2003). See also Baltensperger et al. (2001).

[5] Meyer (1999) also notes that the determinants of inflation may vary with the forecast horizon.

[6] See Gerlach (2003, 2004), Neumann (2003), Neumann and Greiber (2004) and Assenmacher-Wesche and Gerlach (2006).

future. Gerlach-Kristen (2006) finds that this two-pillar approach provides a useful description of the inflation process also in Switzerland.

The SNB's and the ECB's views of the price-formation process is of interest for two reasons. First and as noted above, they raise the question of how to incorporate monetary aggregates with other variables in analysing inflation. Is this best done by modelling inflation with monetary and non-monetary models separately and then forming a judgement of its likely evolution, or is it better to incorporate all driving factors in a single model of inflation? If so, how should that be done?

Second, the notion that the determinants of inflation vary across time horizons raises questions about how to perform the econometric analysis. It seems natural to interpret this hypothesis as stating that the factors driving inflation vary across frequencies and to conduct the analysis in the frequency domain using spectral regression techniques. While these methods have a long history in econometrics, there are surprisingly few applications of them in the recent literature. One reason for this is no doubt that there is a paucity of propositions in economics in which differences across frequency bands play a critical role.

We highlight that the association of the long (short) run with low (high) frequencies that we rely on in this paper is loose. To understand our reasoning, consider the hypothesis that "money growth causes inflation in the long run." This is commonly tested by estimating cross-sectional regressions for the average rate of inflation in country j over some time period on the average rate of money growth in the same period, and testing whether the parameter on money growth is unity.[7] One can interpret these regressions as testing whether there is a unit relationship between money growth and inflation at the zero frequency. Of course, one can generalise this procedure and test for a relationship at other frequency bands, either by performing regressions in frequency domain or by performing the equivalent regression in the time domain, using filtered data (see Engle 1974). Indeed, as we discuss in Section 3, many authors have interpreted long-run propositions in monetary theory as pertaining to the low-frequency behaviour of various aggregates.

One important implication of thinking of the effects of money growth in terms of frequency bands rather than time horizons arises from the fact that a time series at any point in time consists of both high and low-frequency components. If money growth matters for inflation at low frequencies, it must then matter for inflation at every point in time and be relevant for

7 Gerlach (1995) surveys a number of papers that tests the quantity theory in this way.

forecasting inflation at all time horizons. Basing such forecasts solely on higher-frequency variables, such as measures of the cyclical state of the economy and cost-push shocks, thus disregards important information.[8]

Before proceeding, we also emphasise that we do not study the ability of New Keynesian Phillips curve (NKPC) models to explain movements in inflation in Switzerland. The reason for not doing so is that our primary interest is to explore how well the view of the inflation process underlying the monetary policy strategy of the SNB and the ECB fits the data. That view emphasises the role of low-frequency variations of money growth in explaining gradual changes over time in the steady-state rate inflation. In contrast, NKPC models characterise the behaviour of inflation around an assumed steady state, the determination of which is not studied explicitly. Moreover, the ability of NKPCs to fit the data remains sufficiently controversial for it to be undesirable to disregard other research directions.[9] While we recognise that the NKPC has become the dominant theoretical model for analysing inflation, our goals go beyond merely exploring whether or not that model fits the data.[10]

In this paper we study the in-sample relationship between inflation, money growth and the output gap in Switzerland, focussing on the importance of distinguishing between frequency bands. In Section 2 we propose a simple empirical, reduced-form model of inflation and go on in Section 3 to provide a brief review of the related literature using frequency-domain methods. The hall-mark of the model is that at low frequencies inflation is determined by money growth (perhaps relative to the growth rate of real output) while at higher frequencies, inflation is determined by the output gap. In Section 4 we present the data and in Section 5 we briefly discuss the band spectral estimators of Engle (1974), which we use to estimate the model, before turning to the results. While these are broadly supportive of the model, we reject the standard “proportionality result” of the quantity theory, that is, that a one percent increase in money growth leads to an equal increase in inflation. We argue that this finding is due to the fact that changes in the interest rate do not capture fully the strong, negative correlation of money growth with changes in velocity in the sample.

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8 Of course, low-frequency variables evolve by definition slowly over time and, empirically, their contribution to near-term changes in inflation may be limited. This may be why empirical models of inflation frequently disregard monetary factors.

9 See the special September 2005 issue of the Journal of Monetary Economics for a number of papers that explore the empirical performance of NKPCs. For a critical survey, see Rudd and Whelan (2005).

10 Jansen (2004) compares four inflation models on euro area data, including a hybrid NKPC model, and finds that those that use broader information sets including monetary variables forecast better.

Since the finding that money growth is associated with inflation is silent on the important issue of causality, in Section 6 we apply the recently proposed method of Breitung and Candelon (2006) to test for causality across frequency bands. Perhaps not surprisingly, we find that at very low frequencies there is unidirectional causality from money growth to inflation. Around the business cycle frequency of about 5 years, there is unidirectional causality from the output gap to inflation. These findings are highly supportive of the attention paid by the SNB to the behaviour of the monetary aggregates in setting policy. Finally, Section 7 concludes.

2. An empirical model of inflation

Next we turn to the model. We interpret the description by Jordan et al. (2001) of the SNB's monetary policy strategy as stating that the determinants of inflation vary by frequency. Under this view, the monetary analysis is intended to understand the low-frequency movements, or variations in the "local steady-state" rate, of inflation and the analysis of the real indicators seeks to predict temporary swings in inflation around that steady state. To formalize this view, we first decompose "headline" inflation, π_t, into low- (*LF*) and high-frequency (*HF*) components:

(1) $$\pi_t = \pi_t^{LF} + \pi_t^{HF} .$$

Following Gerlach (2003), we hypothesise that the high-frequency movements of inflation are related to movements in the output gap, g_t. A more elaborate model would control for cost-push shocks arising from unit labour costs, exchange rate changes, value-added taxes etc.[11] As is common in the literature, we assume a time lag of one period between the variables:

(2) $$\pi_t^{HF} = \alpha_g g_{t-1} + \varepsilon_t^{HF} .$$

Next, we assume that the low-frequency variation of inflation can be understood in terms of the quantity theory of money:

(3) $$\pi_t^{LF} = \alpha_\mu \mu_t^{LF} + \alpha_\gamma \gamma_t^{LF} + \alpha_\nu \nu_t^{LF} ,$$

where μ_t, γ_t and ν_t denote the growth rate of money and real output, and the rate of change of velocity. Of course, equation (3) is an identity that can be used to define velocity (that is,

[11] Assenmacher-Wesche and Gerlach (2007) find that these variables influence euro area inflation at frequencies of above 6 quarters.

$\alpha_\mu = -\alpha_\gamma = \alpha_\nu = 1$). We assume that the change in velocity depends on the change of the short-term interest rate, ρ_t:

(4) $$\nu_t = \tilde{\alpha}_\rho \rho_t + \varepsilon_t^\nu .$$

The full model, which comprises an error term and therefore constitutes a regression equation, is given by:

(5) $$\pi_t = \alpha_\mu \mu_t^{LF} + \alpha_\gamma \gamma_t^{LF} + \alpha_\rho \rho_t^{LF} + \alpha_g g_{t-1} + \varepsilon_t ,$$

where $\varepsilon_t \equiv \alpha_\nu \varepsilon_t^{\nu,LF} + \varepsilon_t^{HF}$ and $\alpha_\rho \equiv \alpha_\nu \tilde{\alpha}_\rho$. Under the quantity theory, and provided that money growth is uncorrelated with velocity shocks, ε_t^ν, at low frequencies (that is, μ_t^{LF} and $\varepsilon_t^{\nu,LF}$ are orthogonal), we expect to be unable to reject the joint hypothesis that $\alpha_\mu = -\alpha_\gamma = 1$. Moreover, we expect to obtain positive coefficients on the lagged output gap and the low-frequency change in the interest rate; the latter arising from $\alpha_\nu = 1$ and the fact that theory suggests a positive relation between velocity and the interest rate. Under this interpretation of the SNB's monetary policy strategy, it would seem appropriate to focus on low-frequency (as opposed to "headline") movements in money growth and on the output gap in analysing inflation.

Before proceeding, we emphasize that the inflation equation proposed above is entirely empirical. To understand what it says about the monetary transmission mechanism, consider first the short-run correlation between money growth and inflation. Our view is that movements in money growth are correlated with shifts in aggregate demand, which in turn impact on the output gap and therefore on inflation. However, since money growth is partially due to temporary shifts in money demand and changes in the financial system that may not impact on inflation, perhaps because they are not of sufficient duration to do so, it is an empirical question whether the effects of money on aggregate demand at high frequencies are best measured by data on money growth or measures of the output gap.[12] An additional reason for believing that money growth is not a sufficient statistic for aggregate demand at high frequencies is that there are other factors that have temporary demand effects such as changes in fiscal policy. Thus, a finding that the output gap, but not money growth, impacts on high-frequency swings in inflation does not imply that money growth is unimportant for inflation in the short run.

[12] See also the discussion in Nelson (2003).

By contrast, the effects of money growth on inflation are likely to be clearer at low frequencies. First, economic theory suggests that monetary disturbances have at most short-run effects on real variables such as the output gap. It is therefore unlikely that the output gap will capture the low-frequency effects of a shift in the money growth rate. Second, the output gap is by construction stationary while inflation may display a unit root, perhaps arising from occasional shifts in the inflation regime. This difference in the time-series properties suggests that one would not expect inflation and the output gap to be closely related at low frequencies. Rather, shifts in the money growth rate, which should be tied to changes in the inflation regime, are likely to be informative about gradual variations over time in the average level of inflation.

3. Related literature

To understand how the research presented below ties in with the existing literature, it useful to briefly review some related work. Since many authors have interpreted the covariation between macroeconomic time series at low frequencies as capturing the "long-run" links between them, frequency-domain techniques have been used to test various neutrality propositions from monetary theory. For instance, Lucas (1980), Thoma (1994), Jaeger (2003), Haug and Dewald (2004) and Benati (2005) investigate the relationship between money growth and inflation at different frequency bands. Geweke (1986) studies a century of annual US data and finds that at low frequencies money growth is structurally superneutral with respect to output and the real rate of return, but not with respect to velocity. Summers (1983) uses band spectrum regressions to study the low-frequency relationship between inflation and interest rates but finds no evidence of a Fisher effect. Bruggeman et al. (2005) estimate a structural filter model and use this to extract the underlying growth trend of M3 in the euro area. They argue that it plays an important role in inflation developments. Table 1 contains more detailed information about the data used, the countries covered and the econometric approach in these studies.

This literature is best seen as studying the dynamic relationships between money growth and inflation in an atheoretical manner. Similarly, in a study closely related to this, Assenmacher-Wesche and Gerlach (2006) estimate a Phillips curve model, using the band spectral estimator proposed by Phillips (1991) for non-stationary data.[13] The underlying hypothesis is that there is a one-to-one relationship between inflation and money growth at low frequencies but that at

[13] This appears to be one of the first uses of Phillips' estimator in the applied econometric literature, except for Corbae et al. (1994) and Hall and Trevor (1993).

high frequencies inflation is determined by the output gap. Estimating the model on quarterly euro-area data for 1971-2005, the authors do not reject this hypothesis. They argue that this finding is compatible with the idea that the determination of inflation varies across frequency bands, a hypothesis that the ECB has used to motivate its choice of a two-pillar framework for monetary policy.[14] Assenmacher-Wesche and Gerlach (2007) extend this analysis by incorporating cost-push shocks at the highest frequencies.

4. Data

The econometric work discussed below is conducted on seasonally unadjusted quarterly data from 1970Q1 to 2006Q2.[15] All series are mean-adjusted and, except for the three-month interest rate, are in natural logarithms. The interest rate is expressed as $0.25\ln(1+r/100)$, where r is the interest rate in percent per annum, to make it compatible with the units of measurement of the rate of inflation. Figure 1 shows the data. Inflation, in the upper left-hand panel, is defined as the quarterly growth rate of the consumer price index (CPI).[16] Money growth, in the mid left-hand panel, is measured as the quarterly growth rate of the monetary aggregate M3.[17] Inflation shows several sharp rises in the 1970s and 1980s, which were preceded by similar increases in the growth rate of money. Since the mid-1990s, however, inflation has remained virtually constant at around 0.25 percent per quarter. The interest rate is the three-month LIBOR rate. The lower left-hand panel shows the change in the interest rate, which, like inflation, shows higher volatility in the first part of the sample period.

The upper right-hand panel of Figure 1 shows real output growth, measured by the quarterly change in real gross domestic product. The graph shows that output has a strong seasonal component which conceals the fact that output growth was highly volatile in the 1970s, but has subsequently become much more stable.

The output gap, which is plotted in the lower right-hand panel, is defined as output relative to a smooth trend and inherits the seasonal pattern from the output series. While most

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[14] For a discussion of how the determination of inflation in the euro area might differ across time horizons and frequency bands, see ECB (2003). See also Gerlach (2004).

[15] Hecq (1998) argues that standard seasonal adjustment procedures may induce spurious common cycles. With an unbiased seasonal adjustment procedure, results for frequency bands below the annual frequency will be unaffected by the use of seasonally adjusted or unadjusted data.

[16] As changes in the sampling procedure of the Federal Statistical Office in 2000 and 2002 affected the seasonal behaviour of the subindex for clothing and footwear, we seasonally adjusted it before recomputing the CPI. For details, see Assenmacher-Wesche (2006).

[17] Gerlach-Kristen (2006) conjectures that M3 is more informative about inflation than M2 because broader aggregates are not subject to substitution effects between sight and time deposits induced by interest rate changes.

researchers use the Hodrick-Prescott (HP) filter to construct trend output, we filter output in the frequency domain and define the output gap as comprising output variations with a periodicity of more than 48 quarters.[18] Except for at the beginning of the sample, the output gap computed with the spectral filter is very similar to the HP-filtered output gap, as evidenced by a correlation coefficient of 0.81.

Next, we perform unit root tests to investigate the time-series characteristics of the data. As inflation and money growth are possibly non-stationary and unit root tests are known to have low power in the case of a root close to unity, we employ several tests. While the null hypothesis in case of the Augmented Dickey Fuller (ADF) test, the Phillips-Perron (PP) test and the Elliot, Stock and Rotenberg (ERS) test is that the variable tested is non-stationary, the null hypothesis for the KPSS test is stationarity.[19]

Table 2 shows the results, allowing for a constant but no trend in the tests. The lag length for the tests was chosen by the Schwarz information criterion (SIC), considering a maximum of 8 lags.[20] Thus, using a 5% significance level, the PP, the ERS and the KPSS test lead us to conclude that inflation is stationary, while the ADF test points to non-stationarity. For money growth, output growth, the output gap and the interest-rate change all tests indicate stationarity. Looking at Figure 1 one might conclude that the time-series properties of the data have changed over the sample period. We therefore perform the Andrews and Ploberger (1994) test for a structural break in the ADF regression and cannot reject stability except for the residual variance of the change in the interest rate. Because the majority of the tests favours stationarity, we proceed by considering all series as I(0).[21]

Since the model in Section 3 implies that the determinants of inflation vary by frequency, we next present some preliminary graphical evidence suggesting that this is indeed the case. The left-hand panel of Figure 2 shows low-frequency inflation and money growth (defined as the variation in these time series with a periodicity of more than 8 years). It is apparent that about 3 years after a peak in money growth also the inflation rate reaches a maximum.[22] The right-hand panel of Figure 2 shows a scatter plot of inflation versus money growth in the frequency

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[18] Though real output is non-stationary and covariances of a non-stationary series are not well-defined, a frequency-domain filter correctly eliminates the part of the series outside the chosen band (Den Haan and Sumner 2004). To minimize possible endpoint problems, we used all available output data, starting in 1965 and extended the series with a univariate forecast at the end of the sample.

[19] The unit root tests are discussed in Maddala and Kim (1998).

[20] The conclusions from the ADF tests remain the same when the lag length is chosen by the Akaike information criterion or by general-to-specific modelling, though the number of lags chosen differs.

[21] Theory suggests that money growth and inflation are integrated of the same order.

[22] Many studies show that in Switzerland the transmission from money to prices is completed only after 3 years, see Meyer (1999), Jordan et al. (2001) and SNB (2005).

band between 8 years and 6 quarters, which is conventionally regarded as the business cycle frequency, see e.g. Baxter and King (1999). While the low-frequency components of money growth and inflation move together, no corresponding relation exists among the high-frequency components of the series.

Figure 3 provides the same information for inflation and the output gap. Interestingly, until the 1990s the output gap seems to have explanatory power for the low frequencies as well as for the high frequencies. This contrasts with the evidence for the euro area, where inflation is more clearly non-stationary and the output gap is therefore unable to explain shifts in the steady-state rate of inflation (see Assenmacher-Wesche and Gerlach, 2006).

Next we turn to the econometric work.

5. Empirical Methods and Results

In this section we estimate band spectrum regressions, which allow the relation between a set of variables to differ between frequencies. This technique is particularly appropriate for the present case, in which we hypothesise that the output gap matters for inflation at high frequencies, while money and real income growth are correlated with inflation only at low frequencies.

Engle (1974) shows that if $y = x\beta + \varepsilon$ is a valid regression model in the time domain, it can be transformed into the frequency domain by applying a Fourier transformation to both the dependent and the independent variables. Denoting the transformed variables as $\tilde{x}$ and $\tilde{y}$, the regression in the frequency domain is $\tilde{y} = \tilde{x}\beta + \tilde{\varepsilon}$. The transformation to the frequency domain does not affect the standard regression results. The estimator, $\hat{\beta}$, can be written as:

(6) $$\hat{\beta} = \left[\sum_{k=0}^{T-1} \hat{f}_{xx}(\omega_k) \right]^{-1} \sum_{k=0}^{T-1} \hat{f}_{xy}(\omega_k) \,,$$

where T is the sample size, $\hat{f}_{xx}(\omega)$ is the periodogram of the series in x at each frequency ω and $\hat{f}_{xy}(\omega)$ is a vector of cross periodograms.[23] The benefit of transferring the regression model into the frequency domain is that it permits a test of the hypothesis that a specific model applies to some but not to all frequencies. In this case we premultiply the regression

[23] Since the estimator of β averages over periodgrams, there is no need to smooth these as is necessary when estimating the spectrum.

model by a $T \times T$ matrix A with unity on the diagonal for each included frequency and zero elsewhere,

$$(7) \qquad A\tilde{y} = A\tilde{x}\beta + A\tilde{\varepsilon}, \text{ where } E(A\tilde{\varepsilon})(A\tilde{\varepsilon})^* = \sigma^2 A$$

with an asterisk, "*", denoting the complex conjugate of the transposed matrix. Thus, to compute $\hat{\beta}$ we sum over a frequency band instead of the full range of frequencies as in equation (6).[24] If equation (6) is estimated only for a subset of frequencies, but is true for all frequencies, the estimator is consistent but inefficient as it does not use all available information. By contrast, if the model applies only to a specific frequency band, using information from all frequencies might obscure the relationship between the variables. For example, if only low-frequency shifts in money growth lead to proportional increases in inflation, confining the regression to this frequency band is likely to lead to more efficient estimates of the coefficient on money growth. Engle (1974) shows that a conventional F-test can be used to test for equality of the parameters across frequency bands.

5.1 Band spectral estimates

To investigate the relation between inflation and money growth at different frequency bands we consider the equation:

$$(8) \qquad \pi_t^i = \alpha_0^i + \alpha_\mu^i \mu_t^i + \alpha_\rho \rho_t^i + \alpha_\gamma^i \gamma_t^i + \alpha_g^i g_{t-1}^i + \varepsilon_t^i,$$

where i denotes either the high-frequency (*HF*) or low-frequency (*LF*) band ($i = HF, LF$). As implied by the empirical model presented in Section 2, we expect that money and output growth have an impact on inflation only at low frequencies, and the output gap only at high frequencies. Though Figure 2 suggests that money growth leads inflation by about 12 quarters, we consider contemporaneous money growth in equation (8). The reason we do so is that theory suggests that it is money growth relative to income growth and adjusted for changes in money demand stemming from changes in interest rates, which matters for inflation. Thus, if we lag money growth, we should presumably also lag income growth and interest rate changes. Doing so, however, worsens the overall fit of the equation. While lagging only money growth raises the estimate of the impact of money growth somewhat, the parameter is remains much below unity (both economically and statistically). We therefore

[24] Though the cross-periodograms in equation (6) are complex, $\hat{\beta}$ will be real if the k^{th} frequency component is included along with the $T - k^{\text{th}}$ component.

use contemporaneous money growth and rely on the smoothing implicit in the low-frequency regressions to uncover the relation between money growth and inflation.

Table 3 shows the results of the band spectrum regressions for different frequency bands, using the estimator proposed by Engle (1974). As the residuals display serial correlation, we report Newey-West (1987) corrected standard errors. The first column of the table shows the estimates for a model including all frequencies. Both the money growth rate and the output gap are significant at the 1% level, whereas the coefficient on output growth is significant at the 5% level but has a positive sign and the interest rate change is insignificant. The coefficient on money growth, however, is far from unity. An F-test rejects the hypothesis that the parameters on money and output growth have coefficients of 1 and -1, respectively, with a *p*-value of zero.

Next, we estimate the same regression for a low and a high frequency band, using a threshold of four years. Thus, movements of a periodicity of less than four years are considered as high-frequency fluctuations, whereas cycles of a periodicity of more than four years are included in the low-frequency band. As this choice is arbitrary, we also present results where we partition the sample at a periodicity of half and twice the benchmark, i.e., at two years and at eight years. We transform the series into the frequency domain, perform the filtering, transfer the series back into the time domain, and run the regression. If the matrix A in equation (7) is not full rank, we have to adjust the degrees of freedom in the regression by the number of frequencies that has been filtered out.

Columns 2 to 4 in Table 3 show the results for the low-frequency regression. Money growth and output growth are highly significant at low frequencies. The coefficients move toward the theoretically expected values as the band excludes higher frequencies, but remain significantly below unity in absolute value, except for output growth when the low frequency is defined as periodicities of more than eight years. The interest rate change is significantly positive and increases as the band excludes higher frequencies, indicating that adjusting for velocity changes induced by changes in interest rates is important. As could be expected from the evidence in Figure 3, the output gap has a significant impact on inflation at low frequencies irrespectively of how they are defined. An F-test rejects the hypothesis that money and output growth enter the regression with coefficients of 1 and -1 with a *p*-value of zero, regardless of whether we distinguish between high and low frequency at two, four or eight years.

The last three columns of Table 3 present the results of the band spectrum regression for the high-frequency band. Because of the strong seasonality in output growth we only consider frequency bands up to 1.5 years and thus disregard the highest-frequency fluctuations.[25] Output growth is significant in the 1.5-to-2-year frequency band, but not in the others. By contrast, money growth and interest rate changes are always insignificant. The coefficient on the output gap is positive and significant when the band includes frequencies up to four or eight years. In the 1.5-to-2-year band, however, it is negative and significant. Since this regression includes only a small number of frequency ordinates, this result may be spurious.

Next, we test if the relation between inflation, money growth and output growth differs significantly between two frequency bands. A F-test strongly rejects the hypothesis that the low and high-frequency coefficients are equal except for a split at the two-year frequency, with a test statistic of $F_{4,45} = 1.39$ for a split at the two-year frequency, $F_{4,45} = 4.45$ for a split at the four-year frequency and $F_{4,45} = 14.77$ for a split at the eight-year frequency against a 5% critical value of 2.57.

Overall, these results are broadly compatible with the notion that money growth is the primary determinant of inflation at low frequencies while the output gap is important at high frequencies.

5.2 Velocity shocks

As noted above, the parameter on money growth, while significant, is much below unity whereas the coefficient on output growth is above minus unity.[26] To understand these results, note that we have assumed that the error term in the velocity equation (4) is uncorrelated with the regressors, in particular money growth. Suppose instead that this assumption is wrong. If so, we may think of the shocks to the growth rate of velocity as having incorrectly been omitted from the inflation equation, which we can write:

$$(5') \qquad \pi_t = \alpha_\mu \mu_t^{LF} + \alpha_\gamma \gamma_t^{LF} + \alpha_\rho \rho_t^{LF} + \alpha_v \varepsilon_t^{LF,v} + \alpha_g g_{t-1} + \varepsilon_t^{LF} + \varepsilon_t^{HF}$$

where we think of $\varepsilon_t^{LF,v}$ as an omitted variable. Assuming that the true parameter on money growth, α_μ, is unity, the standard omitted-variables result from econometrics (e.g., Greene 2003, p. 149) then implies that:

[25] Since the quarterly Swiss GDP data are interpolated from annual data using third time series, the seasonal pattern may be unreliable and depend on the methods and series used to do the interpolation.

[26] This part follows Gerlach (1995).

(9) $$\alpha_{\mu} = 1 + \alpha_{v}\left(X_{1}'X_{1}\right)^{-1} X_{1}'X_{2},$$

where α_v denotes the parameter on velocity growth (which is unity by definition), X_1 the vector of variables included in the regression and X_2 is the vector of omitted variables. To see whether the low estimates of α_μ may be due to correlation between money growth and changes in velocity, we calculated the bias correction in equation (9) for the coefficients on money growth and output growth by estimating equation (4) and using the residuals as the omitted variable X_2. The results are shown in the last two lines of Table 3. With the correction we see that now for all frequency bands the coefficients on money growth and output growth are virtually unity and minus unity, as suggested by theory. Of course, since velocity is *defined* using money, output and prices, it is not surprising that controlling for shifts in it leads to a unit coefficient on money growth. However, it does illustrate that the low estimates of α_μ arise from the fact that that changes in interest rates do not fully control for shocks to velocity. Reynard (2006) demonstrates that unless shifts to velocity induced by disinflation are controlled for, US and euro area data incorrectly suggest that there is no proportional effect from money growth to inflation in recent decades.

5.3 A Two-Pillar Phillips Curve

The band spectral regressions discussed above show that the relation between inflation, money and output growth, the interest rate change and the output gap varies by frequency. Money growth seems to be important only at low frequencies, whereas the output gap contains information about inflation at both low and high frequencies. To proceed, we follow Gerlach (2003, 2004), Neumann (2003) and Neumann and Greiber (2004) and estimate an equation for headline inflation with the output gap and the low-frequency components of money growth, output growth and the interest rate change as explanatory variables. Our final inflation equation, which Gerlach (2003, 2004) refers to as "two-pillar Phillips curve", is thus:

(8) $$\pi_t = \beta_0 + \beta_\mu \mu_t^{LF} + \beta_\gamma \gamma_t^{LF} + \beta_\rho \rho_t^{LF} + \beta_g g_{t-1} + \varepsilon_t .$$

In contrast to the regressions in the last section, the dependent variable is in this case not filtered and there is therefore no loss in degrees of freedom. To account for autocorrelation in the residuals we follow three different approaches: we calculate Newey-West (1987) corrected standard errors; we apply Hannan's efficient estimator; and, finally, we include a lagged dependent variable to reduce the degree of autocorrelation. Results using the Newey-

West corrected standard errors are presented in the first panel of Table 4. The first column provides the results for a model that is estimated using as regressors money growth, output growth, the interest rate change and the lagged output gap at all frequencies. The next three columns provide regression results using the unfiltered output gap, since the band spectrum regressions indicated that it has explanatory power at both low and high frequencies, but only the low-frequency components (defined as fluctuations in the regressors with periodicities greater than two, four and eight years, respectively) of the other variables. In contrast to the "all frequencies" regression, the coefficient on money growth is below unity for the reasons just discussed but increases the more high frequencies are filtered out. Moreover, the adjusted R^2 generally increases when the filtered, rather than the unfiltered, variables are used. This supports the notion that the highest frequency bands of money growth contain largely noise of little use for forecasting inflation.

The second part of Table 4 applies the Hannan efficient estimator to the same regression. This procedure allows for arbitrary serial correlation patterns as long as the disturbances are covariance stationary.[27] Again, the first column shows the results for a model that is estimated on money growth, output growth, the interest-rate change and the lagged output gap at all frequencies, while the next three columns include only the low-frequency component of the other regressors. While the coefficients on output growth and the interest-rate change are significant in the four-year frequency band, money growth enters with a significant coefficient on in the eight-year band. Like in the first part of Table 4, the output gap is always significant. In total, however, the use of the Hannan estimator leads to results similar to those obtained using the other approaches. Of course, since the variables are filtered to handle the serial correlation in the residuals, the adjusted R^2s differ.

Finally, we account for the serial correlation by including lagged inflation among the regressors. The results are shown in the third panel of Table 4. Lagged inflation is highly significant in all cases. In the filtered regressions, the coefficient on money growth increases with lower frequency bands while the autoregressive coefficient decreases. The long-run effects of money growth are virtually identical to those in the previous cases.

In sum, the regression results reported in Table 4 confirm that there exists a close link between money and inflation at low frequencies in Switzerland. In addition, movements in the output gap provide information about inflation dynamics.

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[27] The idea is to find a filter that renders the residuals white noise. This filter can be computed as the reciprocal of the square root of the spectral density of the residuals. The dependent and independent variables are then filtered and the regression is run with the transformed variables, see Hannan (1965).

6. Causality between money growth and inflation

While our results indicate that money growth is strongly correlated with current inflation, we have not directly tested the hypothesis that low-frequency movements in money growth cause inflation. To understand properly the inflation process an understanding of the patterns of causality is consequently needed.

We employ the notion of causality introduced by Granger (1969, 1980). Money growth is said to cause inflation if it contains information about future inflation that is not contained in some past values of π. The extent and direction of causality can differ between frequency bands (Granger and Lin, 1995). The fact that a stationary series is effectively the sum of uncorrelated components, each of which is associated with a single frequency ordinate, allows the full causal relationship to be decomposed by frequency.[28]

We investigate causality across frequencies in a vector autoregression (VAR) containing inflation, money growth and the output gap.[29] Since the causal relation between money growth and inflation could be influenced by the output gap, we condition the causality test on this variable. Instead of measuring causality between π_t and μ_t directly, we therefore compute the causality measure for the residuals u_t and v_t obtained by regressing money growth and inflation on the residuals from a regression of the output gap on lagged values of π_t and μ_t.[30] Hosoya (2000) shows that the causality measure from money growth to inflation, given the output gap, is equal to the bivariate causality measure between the projection residuals u_t and v_t,

$$(10) \qquad \begin{bmatrix} u_t \\ v_t \end{bmatrix} = \begin{bmatrix} \Psi_{11}(L) & \Psi_{12}(L) \\ \Psi_{21}(L) & \Psi_{22}(L) \end{bmatrix} \begin{bmatrix} \eta_{1t} \\ \eta_{2t} \end{bmatrix}$$

where the $\Psi_{ab}(L)$, a, b = 1, 2 are polynomials in the lag operator, L, and η_1, η_2 are the orthogonalized shocks.[31] The frequency-wise measure of causality suggested by Geweke (1982) and Hosoya (1991) is defined as:

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[28] Though the component of a series in a certain frequency band cannot be estimated without the use of a two-sided filter which destroys the chronological aspect of the causal definition, it is possible to deduce causal relationships at different frequencies without estimation of the series' components, as it is done in the band spectrum regressions.

[29] See also Granger and Lin (1995) and Breitung and Candelon (2006).

[30] In this regression we include the contemporaneous values of inflation and money growth, since Hosoya (2000) argues that omitting them may lead to a finding of spurious causality. Excluding π_t and μ_t, however, does not alter the results.

[31] That is, the VAR reduced-form errors are transformed into the orthogonalized errors by multiplying them with the lower triangular matrix from a Choleski decomposition of the reduced-form covariance matrix.

(11) $$M_{\mu\to\pi|g} = M_{v\to u}(\omega) = \log\left[1 + \frac{\left|\Psi_{12}(e^{-i\omega})\right|^2}{\left|\Psi_{11}(e^{-i\omega})\right|^2}\right].$$

Money growth Granger-causes inflation if $\Psi_{12}(L)$ is non-zero. Breitung and Candelon (2006) show that the hypothesis $M_{\mu\to\pi}(\omega)=0$ is equivalent to a linear restriction on the VAR coefficients and that its significance can be tested by a conventional F-test. To assess the significance of the causal relationship we compare the causality measure for $\omega \in (0,\pi)$ with the critical value of a χ^2-distribution with 2 degrees of freedom, which is 5.99.

Figure 4 shows the causality measure over frequencies from zero to π. The Akaike, the Schwarz or the Hannan-Quinn criteria all indicate a lag length of 5 for the trivariate VAR underlying the causality test.[32] We find significant causality from money growth to inflation at low frequencies. At frequencies above 0.2π, which corresponds to 10 quarters, no significant causality is found.[33] In contrast, there is no causality from inflation to money growth at any frequency. We also test causality from the output gap to inflation and conversely. The causal relationship from the output gap to inflation is significant for frequencies below 5 quarters and shows a peak at the business cycle frequency of 20 quarters. We thus find that output gaps predict inflation at higher frequencies than money growth. However, the test indicates causality also near the zero frequency, which is surprising since the output gap should have no variation in this frequency band. This finding may be caused by leakage problems when filtering output to obtain the output gap.

7. Conclusions

In this paper we have analysed the behaviour and the determination of inflation in Switzerland across frequency bands, using quarterly data for the period 1970-2006. We emphasise three findings. First, the notion that movements in steady-state inflation depend on long-run money growth and fluctuations around this steady state on the output gap, which underlies both the ECB's two-pillar framework and the SNB monetary policy strategy, is helpful for analysing inflation in Switzerland. However, Switzerland has a history of low and stable inflation in which money growth and velocity changes are negatively correlated. Unless shocks to velocity are controlled for, the parameter on money growth is biased downwards, which

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32 Because of the strong seasonal pattern in the output gap we include quarterly seasonal dummies in the VAR. The causality measure is robust to a variation of the lag length.

33 Measuring frequency, ω, in fractions of π, periodicity in quarters is given by $2\pi/\omega$.

makes it more difficult to find the proportional link between money growth and inflation implied by the quantity theory.

Second, we have demonstrated that causality in the Granger sense runs from money growth to inflation, but not conversely. These findings cast doubts on the notion that the strong correlation between the two variables that we observe in the data merely reflects the existence of a stable money demand function. Rather, it suggests that sustained variations in money growth have over time led to fluctuations in the rate of inflation.

Third, at higher frequencies the output gap causes inflation. This implies that analysing inflation by solely considering the information in the monetary aggregates would forego important information. While the SNB even under the monetary targeting period employed a range of indicators to judge the state of the economy and to set policy, the shift to the new monetary policy strategy has served to clarify that monetary aggregates, while important, are not the only information variables relied on.

Overall, the results provide ample support for the notion that extracting information from money growth is helpful in guarding against the development of inflation pressures and in setting monetary policy in Switzerland.

Several extensions to the analysis presented above appear warranted. In particular, it would be desirable to compare the information content of M2 and M3. Though Gerlach-Kristen (2006) found that M3 is more significant in a Phillips-curve model of inflation, modelling explicitly changes in velocity by incorporating changes in the interest rate in the analysis, as we did in this paper, might allow us to account for the higher interest-rate sensitivity of M2. Furthermore, high-frequency fluctuations in inflation are typically largely due to price-level shocks, coming from changes in taxes, exchange rates, or import, energy or food prices. Incorporating such cost-push shocks in the analysis is likely to reduce the variance of errors and allow for better estimates of the impact of money growth and output gaps on inflation. Finally, the issue of how to best use of the low-frequency information in money growth to construct out-of-sample forecasts of inflation also warrants attention. These extensions we leave for future research.

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Tables and Figures

Table 1
Brief summary of related literature.

Reference	Brief summary	Data	Method
Lucas (1980)	Studies the behaviour of M1 growth, CPI inflation and t-bill rates. Finds a one-to-one relationship between money growth, inflation and nominal interest rates at the lowest frequencies.	Quarterly US data for 1953-1977.	Uses a two-sided moving-average filter to extract low frequency component.
Summers (1983)	Studies the relationship between inflation (using wholesale or consumer prices) and commercial paper yields or long-term bond yields. Finds that Fischer hypothesis does not hold.	Monthly US data for 1860-1939 and 1948-1980	Band spectral regression.
Geweke (1986)	Tests the superneutrality of money growth for real economic activity, the real money stock, real interest rates and velocity (the choice of variables depends on data sets).	US data; Annual for 1870-1970; monthly for 1954-1970.	Develops test for feedback across frequency bands.
Thoma (1994)	Examines responses across frequency bands of t-bill rates and CPI inflation to M1 growth. Causality from money to inflation is highest at relatively high frequencies. Identifies liquidity and expected inflation effects of money growth on interest rates.	Monthly US data for 1959-1989.	Filters data in frequency domain, converts it to time domain and performs multivariate causality tests.
Jaeger (2003)	Finds high coherence between money growth and CPI inflation for cycles longer than 8 years.	Annual data for 1961-1998 for euro-area economies.	Cross-spectral analysis.
Haug and Dewald (2004)	Studies cross-correlations of money growth, nominal and real income growth and inflation. Money growth leads or affects contemporaneously nominal output growth and inflation at low frequencies.	Annual data for 1880-2001 for eleven countries.	Extracts the 2-8 years and 8-40 years frequency bands using band-pass filters.
Benati (2005)	Investigates correlations between inflation and growth rates of narrow and broad money at periodicities of 8-30 years and longer than 30 years. Correlations are very stable at low frequencies.	Quarterly data starting in 1870 for the UK and the US.	Uses band-pass filters to extract the low frequency components.
Bruggeman et al. (2005)	Studies the roles of money growth and output gaps in inflation in the euro-area. Finds that M3 growth matters at the lowest, and the output gap at somewhat higher, frequencies.	Quarterly euro area data for 1986-2003.	Fits money-augmented Phillips curves. Computes implicit low-frequency measures of money growth and output gap.
Assenmacher-Wesche and Gerlach (2006 and 2007).	Estimates inflation equations across frequency bands. Monetary variables are important at low, and output gaps at higher, frequencies. Estimates inflation equation using monetary variables at low, and output gaps at higher, frequencies. Assenmacher-Wesche and Gerlach (2007) also allow for cost-push shocks at the highest frequencies.	Quarterly data for euro area 1971-2005.	Uses band spectral regressions techniques for stationary and non-stationary data.

Table 2. Unit root tests

Sample period: 1970Q1 to 2006Q2.

	ADF	*PP*	*ERS*	*KPSS*	*SIC lag*
Inflation	-2.37	-5.99**	-2.32*	0.07	4
Money growth	-3.27*	-9.42**	-3.33**	0.06	8
Output growth	-5.03**	-30.61**	-3.49**	0.03	3
Output gap	-4.43**	-7.70**	-4.11**	0.10	4
Interest rate change	-8.79**	-8.85**	-8.24**	0.06	0

Note: The last column indicates the number of lags included in the test, which were chosen by the Schwarz information criterion (SIC). The tests include a constant but no trend. The 5% (1%) critical values are -2.89 (-3.48) for the Augmented Dickey-Fuller (ADF) and the Phillips-Perron (PP) test, -1.95 (-2.58) for the Elliot, Stock and Rotenberg (ERS) test and 0.46 (0.74) for the Kwiatkowski, Phillips, Schmidt and Shin (KPSS) test. An asterisk, “*”, indicates the rejection of the null hypothesis at the 5% level.

Table 3. Band spectrum regressions: Engle's estimator

Estimates of $\pi_t^i = \alpha_0^i + \alpha_\mu^i \mu_t^i + \alpha_\rho^i \rho_t^i + \alpha_\gamma^i \gamma_t^i + \alpha_g^i g_{t-1}^i + \varepsilon_t^i$

Sample period: 1970Q1 to 2006Q2.

	0.5 to ∞ years	*2 to ∞ years*	*4 to ∞ years*	*8 to ∞ years*	*1.5 to 2 years*	*1.5 to 4 years*	*1.5 to 8 years*
Money growth	0.14**	0.23**	0.33**	0.57**	-0.09	0.02	-0.07
	(0.04)	(0.06)	(0.06)	(0.05)	(0.05)	(0.05)	(0.04)
Output growth	0.03*	-0.31*	-0.56**	-0.94**	-0.14*	0.10	0.09
	(0.01)	(0.14)	(0.13)	(0.13)	(0.06)	(0.05)	(0.06)
Interest rate change	0.38	1.28**	2.15**	5.21**	0.23	-0.35	0.33
	(0.39)	(0.49)	(0.54)	(0.79)	(0.20)	(0.27)	(0.22)
Output gap (*t*–1)	0.12**	0.15**	0.15**	0.18**	-0.30**	0.09**	0.09**
	(0.02)	(0.02)	(0.01)	(0.01)	(0.06)	(0.02)	(0.02)
$\bar{R}^2$	0.31	0.56	0.67	0.85	0.10	0.06	0.28
Degrees of freedom	142	33	14	5	9	27	36
Money growth (bias corr.)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Output growth (bias corr.)	-1.00	-1.00	-1.00	-0.98	-1.00	-1.00	-1.00

Note: The dependent variable is the inflation rate at the respective frequency band. All regressions include a constant which is not shown. Newey-West (1987) corrected standard errors in parentheses; * indicates significance at the 5%, ** significance at the 1% level.

Table 4. Two-pillar Phillips curves

Estimates of $\pi_t = \beta_0 + \beta_\mu \mu_t^{LF} + \beta_\rho \rho_t^{LF} + \beta_\gamma \gamma_t^{LF} + \beta_g g_{t-1} + \varepsilon_t$

Sample period: 1970Q1 to 2006Q2.

	0.5 to ∞ years	*Filtered 2 to ∞ years*	*Filtered 4 to ∞ years*	*Filtered 8 to ∞ years*	*0.5 to ∞ years*	*Filtered 2 to ∞ years*	*Filtered 4 to ∞ years*	*Filtered 8 to ∞ years*
Approach to control for serial correlation in the residuals:	Newey-West standard errors				Hannan's efficient estimator			
LF money growth	0.14**	0.22**	0.32**	0.53**	0.07	-0.03	0.16	0.62**
	(0.04)	(0.07)	(0.08)	(0.11)	(0.04)	(0.08)	(0.11)	(0.11)
LF output growth	0.03	-0.31	-0.52**	-0.81**	0.03*	-0.15	-0.40*	-0.54
	(0.01)	(0.18)	(0.19)	(0.24)	(0.01)	(0.13)	(0.18)	(0.33)
LF interest rate change	0.38	1.34	2.35**	5.27**	0.28	0.65	1.76*	3.64
	(0.39)	(0.76)	(0.86)	(1.45)	(0.16)	(0.50)	(0.80)	(2.17)
Output gap (*t*–1)	0.12**	0.11**	0.11**	0.12**	0.11**	0.09**	0.09**	0.11**
	(0.02)	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)
$\bar{R}^2$	0.31	0.31	0.38	0.44	0.17	0.16	0.17	0.34
Durbin-Watson	1.17	1.38	1.50	1.76	2.00	2.02	1.97	1.99

Note: The dependent variable is the headline inflation rate. All regressions include a constant which is not shown. Standard errors in parentheses; * indicates significance at the 5%, ** significance at the 1% level.

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Table 4 (cont.). Two-pillar Phillips curves

Estimates of $\pi_t = \beta_0 + \beta_\mu \mu_t^{LF} + \beta_\rho \rho_t^{LF} + \beta_\gamma \gamma_t^{LF} + \beta_g g_{t-1} + \varepsilon_t$

Sample period: 1970Q1 to 2006Q2.

	0.5 to ∞ years	*Filtered 2 to ∞ years*	*Filtered 4 to ∞ years*	*Filtered 8 to ∞ years*
Approach to control for serial correlation in the residuals:	Allowing for lagged dependent variable			
LF money growth	0.11**	0.13*	0.20**	0.36**
	(0.04)	(0.06)	(0.07)	(0.09)
LF output growth	-0.01	-0.13	-0.28*	-0.52**
	(0.01)	(0.10)	(0.12)	(0.20)
LF interest rate change	0.44*	0.82*	1.51**	3.68**
	(0.20)	(0.43)	(0.55)	(1.31)
Output gap (*t*–1)	0.07**	0.07**	0.07**	0.09**
	(0.02)	(0.01)	(0.01)	(0.01)
Lagged inflation	0.47**	0.44**	0.39**	0.34**
	(0.07)	(0.07)	(0.07)	(0.07)
$\overline{R}^2$	0.49	0.46	0.48	0.51
Durbin-Watson	2.09	2.14	2.13	2.20

Note: The dependent variable is the headline inflation rate. All regressions include a constant which is not shown. Standard errors in parentheses; * indicates significance at the 5%, ** significance at the 1% level.

Figure 1. Data

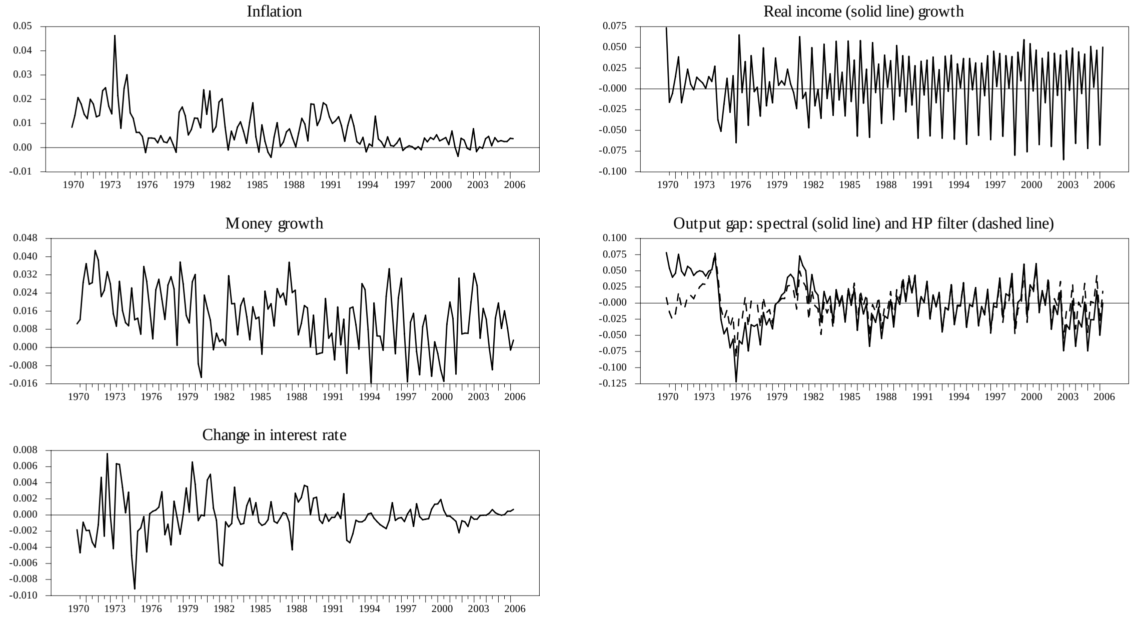


Figure 2. Inflation and money growth at low and high frequency

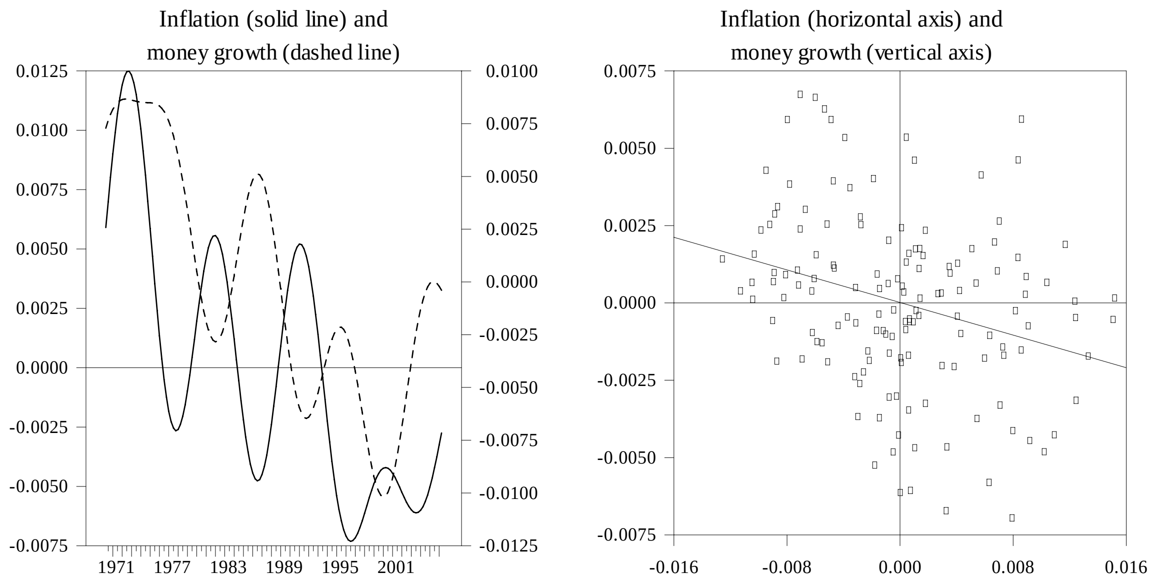


Figure 3. Inflation and output gap at low and high frequency

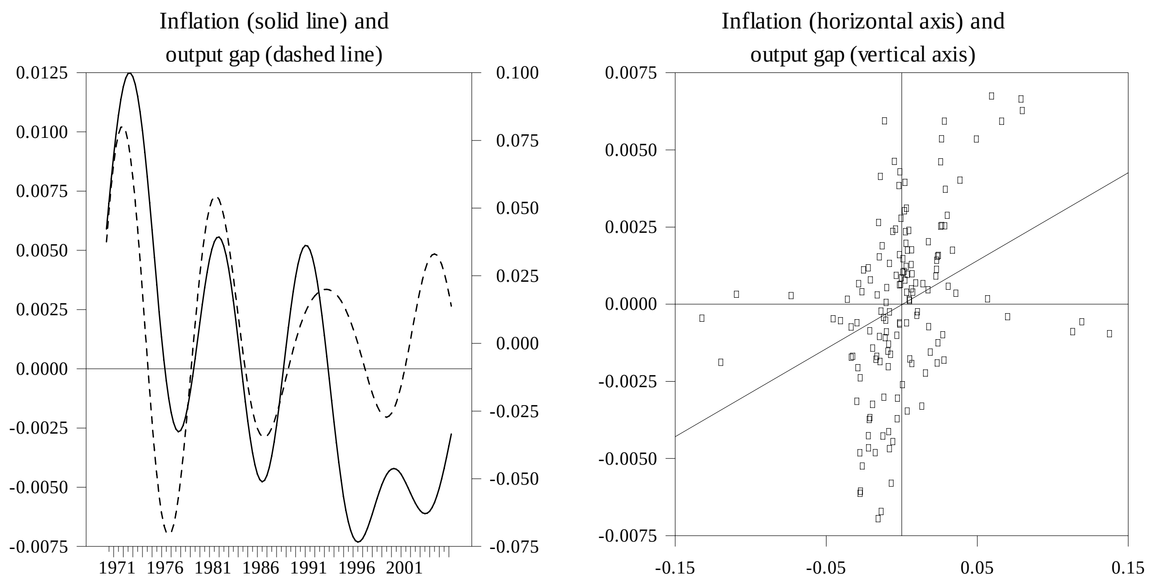
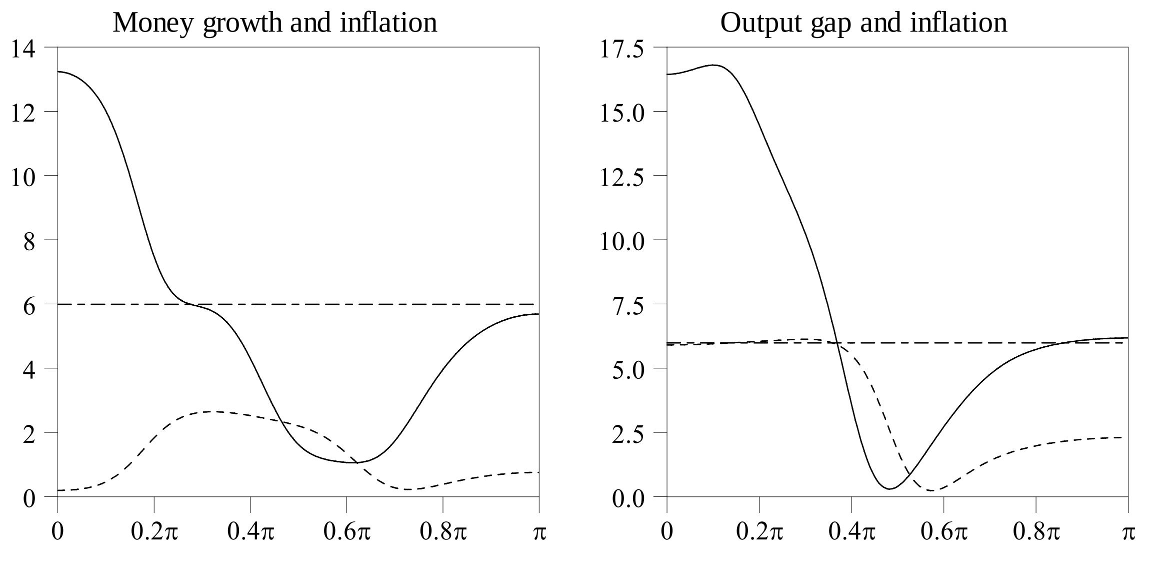


Figure 4. Causality



Note: The solid line shows the causality measure from money growth and the output gap to inflation, the dashed line the causality measure from inflation to the respective variable. The causality measures are derived from a trivariate VAR including inflation, money growth, and the output gap. The horizontal line shows the 5% critical value. The horizontal axis shows the frequency ordinates as fractions of π.