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ABSTRACT

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

While monetary targeting has become increasingly rare, many central banks attach weight to money growth in setting interest rates. This raises the issue of how money can be combined with other variables, in particular the output gap, when analysing inflation. The Swiss National Bank 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. Using band spectral regressions and causality tests in the frequency domain, we show that this interpretation of the inflation process fits the data well.

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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 introduced a new monetary policy strategy, or “*concept*”, 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 was 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 adopt a new concept without a monetary target. One reason why this was felt desirable was that it enabled the SNB to make clearer that policy was conducted using a broad range of indicators rather than being narrowly restricted to information embedded in the monetary aggregates.

The new concept is based on three elements: 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 at a quarterly frequency 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 three subsequent years, which corresponds to the time the SNB believes is required for policy actions to be transmitted to the economy.

¹ See the statement of Meyer (1999), in which the new concept was announced, and SNB (2005) for more information. Genberg and Kohli (1997), Peytrignet (2000) 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.

Money plays no privileged role in the new framework. However, given the central role of the inflation forecast, all variables that impact on the outlook for prices are incorporated in the policy analysis. Monetary aggregates remain important 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 shorter 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 concept, it is instructive to consider the views of Jordan, Peytrignet and Rich (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 are operative (ECB, 2003, Gerlach, 2004, and Assenmacher-Wesche and Gerlach, 2006). In the literature a number of authors have formalised the ECB’s conception of the determination of inflation using a Phillips curve augmented with a term capturing the low-frequency movements in the growth rate of M3. 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 future.⁶ Gerlach-Kristen (2005) finds that this two-pillar approach provides a useful description of the inflation process in Switzerland.

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).

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 best be done?

Second, they raise interesting econometrics questions since the notion that the determinants of inflation vary across time horizons plays such a central role in them. This implies that it is natural to conduct the analysis in the frequency domain. While spectral techniques 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.

In this paper we study the relationship between inflation, money growth and the output gap in Switzerland, focussing on the importance of distinguishing between frequency bands. In Section 2 we provide a brief review of the related literature using frequency-domain methods and go on in Section 3 to propose a simple empirical, reduced-form model of inflation. The hall-mark of the model is that at low frequencies, or, loosely speaking, in the long run, inflation is determined by money growth (perhaps relative to the growth rate of real output) while in the short-run or at higher frequencies, inflation is determined by the output gap. In Section 4 we present the data and perform a preliminary cross-spectral analysis of money growth and inflation, and of the output gap and inflation which allows us to discuss the strength of associations between these variables at different frequencies. In Section 5 we briefly discuss the band spectral estimator of Engle (1974), which we use to estimate the model, before turning to the results. While these are broadly supportive of the model, we can 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 we disregard the strong, negative correlation of money growth with changes in velocity in the sample.

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 (2005) to test for causality across frequency bands. Perhaps not surprisingly, we find that at very low frequencies money growth causes inflation, but that the converse is not true. At higher frequencies, there is causality from the output gap to inflation. These findings

are highly supportive of the attention paid by the SNB in the past and currently to the behaviour of the monetary aggregates in setting policy. Finally, Section 7 concludes.

2. Related literature

To understand how the research presented below ties in with the existing literature, it is useful to briefly review some related work. Since many authors have interpreted the covariation between macroeconomic time series at low frequency as capturing the “long run” links between them, frequency-domain techniques have been used to test various neutrality propositions from monetary theory. Lucas (1980), Thoma (1994), Jaeger (2003), Haug and Dewald (2004) and Benati (2005) thus investigate whether there is a one-to-one relationship between money growth and inflation at low frequencies, and generally conclude that this is the case. 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.⁷ Bruggeman et al. (2005) use frequency domain filtering to extract the underlying growth trend of M3 in the euro area and argue that it plays an important role in inflation developments.

These papers are best seen as studying the dynamic relationships between money growth and inflation in an atheoretical manner. Similarly, Assenmacher-Wesche and Gerlach (2006) estimate a Phillips curve model, using the band spectral estimator proposed by Phillips (1991) for non-stationary data.⁸ The underlying hypothesis is that there is a one-to-one relationship between money growth and inflation at low frequencies but that at high frequencies inflation is determined by the output gap.⁹ Estimating the model on quarterly euro-area data for 1971-2004, 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.¹⁰

⁷ Cochrane (1989) uses the Engle (1974) estimator to ask whether high-frequency movements in money growth depress interest rates in the US, as would be expected if there was a liquidity effect.

⁸ 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).

⁹ Engle (1978) uses data from 16 US cities and finds that the relationship between the food price component of the CPI and labour costs in the food industry is closer at low than at high frequencies. Interestingly, the converse is true for the relationship between the food price component of the CPI and the wholesale price index for food and processed feeds.

¹⁰ 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).

3. An empirical model of inflation

Next we turn to the model. We interpret the description by Jordan, Peytrignet and Rich (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 short-run 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:

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

Following Gerlach (2003), we hypothesise that the high-frequency movements of inflation are related to movements in the output gap, g_t .¹¹ As is common in the literature, we assume a time lag of one period between the variables:

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

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

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

where μ_t , γ_t and ν_t denote the growth rate of money and real output, and the rate of change of velocity. We assume that the change in velocity depends on the change of the short-term interest rate, ρ_t :

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

At low frequencies, the growth rate of real output is identical to the growth rate of potential. 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 that $\alpha_\mu = -\alpha_\gamma = 1$. The full model is given by:

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

¹¹ Of course, a more elaborate model would need to control for cost-push shocks arising from unit labour costs, exchange rate changes, value-added taxes etc.

where $\varepsilon_t = \varepsilon_t^{LF} + \alpha_v \varepsilon_t^{v,LF} + \varepsilon_t^{HF}$ and $\alpha_\rho \equiv \alpha_v \tilde{\alpha}_\rho$. 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 short-run effects of money on aggregate demand 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 in the short run 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 short-run movements in inflation.

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 temporary effects on real variables such as the output gap. It is therefore unlikely that the output gap will capture the long-run 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 in the long run. Rather, shifts in the money growth rate, which should be tied to changes in the inflation regime, are likely to be informative about variations over time in the average level of inflation.

Next we explore the relationships between inflation, money growth, real income growth and the output gap in different frequency bands.

¹² See also the discussion in Nelson (2003).

4. Data

The econometric work discussed below is conducted on quarterly data from 1970Q1 to 2005Q2. All series except for the three-month interest rate are in natural logarithms and mean-adjusted. The interest rate is expressed as $0.25 \ln(1 + r/100)$, where r is the interest rate in percent p.a., 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).¹³ Money growth, in the mid left-hand panel, is measured as the quarterly growth rate of the monetary aggregate M3.¹⁴ 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 1 percent. 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, together with trend output growth. To obtain the latter, we filter output growth in the frequency domain and define trend output growth as comprising only output growth variations with a periodicity of more than 48 quarters. The graph shows that while output growth was highly volatile in the 1970s, it 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. While most researchers use the Hodrick-Prescott (HP) filter to construct trend output, we use our filtered measure of trend output growth. However and perhaps not surprisingly, the output gap computed with the spectral filter is very similar to the HP-filtered output gap, as evidenced by a correlation coefficient of 0.95.

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

¹³ 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 the subindex before adding it back to the total CPI. For details, see Assenmacher-Wesche (2005).

¹⁴ Gerlach-Kristen (2005) conjectures that M3 is more informative about inflation than M2 because it is less subject to substitution effects between sight and time deposits induced by interest rate changes.

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.¹⁵

Table 1 shows the results, allowing for a constant but no trend in the tests. The results are mixed. Thus, using a 5% significance level, the PP and the ERS test lead us to conclude that inflation is stationary, while the ADF and the KPSS test point to non-stationarity. Similarly, the ADF, PP and ERS tests suggest that money growth is stationary, but the KPSS-test indicates non-stationarity.¹⁶ For output growth, the output gap and the interest rate change the tests do all indicate stationarity. Overall, we interpret these tests as suggesting that all variables can be thought of as stationary, in particular since the power of the tests is low.

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.¹⁷ The right-hand panel of Figure 2 shows a scatter plot of inflation versus money growth in the frequency 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.¹⁸

Figure 3 provides the same information for inflation and the output gap. Interestingly, 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 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).

We interpret Figures 2 and 3 as indicating that there are strong links between the time series in the low-frequency band. To assess this hypothesis more formally, we perform a cross-spectral analysis for inflation, money growth and the output gap.¹⁹ Cross-spectral analysis

¹⁵ The ADF and PP tests are discussed in Hamilton (1994), the ESR test in Elliot, Stock, and Rotenberg (1996), and the KPSS test in Kwiatkowski et al. (1992).

¹⁶ Adding a trend to the unit-root regression makes the KPSS test unable to reject stationarity for inflation and money growth. All other test results remain unchanged.

¹⁷ Many analyses have shown that for Switzerland the transmission from money to prices is completed only after 3 years, see Meyer (1999), Jordan, Peytrignet and Rich (2001) and SNB (2005).

¹⁸ While we would expect a relation between money and inflation at the business cycle frequency, Benati (2004) shows that the correlation between these variables has changed sign in the second half of the 1980s.

¹⁹ We thank Luca Benati for providing us with the compute code to estimate the partial cross spectra.

permits an investigation of the relationship between two time series at different frequencies. As the cross spectrum is a complex number, it is generally decomposed into its two real-valued constituents – the co-spectrum and the quadrature spectrum – which then are used to compute the coherence and the gain. The coherence can be thought of as the R-squared in a regression, by frequency, of y on x . The gain, which is the ratio of the covariance of y and x to the variance of x , can be thought of as the absolute value of the slope parameter in such a regression.

Figure 4 shows the gain and the coherence for inflation and money growth. The upper panel shows the measures based on the full spectral density matrix for inflation and money growth while the lower panel shows the partial gain and the partial coherence, controlling for output growth and the change in the interest rate. The horizontal axis measures the frequency in fractions of π .²⁰ The frequencies can be converted to periodicity as follows: letting ω denote frequency, measured by cycles per quarter, the periodicity, p , measured in quarters, is given by $2\pi/\omega$.²¹ Thus, a frequency of 0.5π corresponds to a periodicity of 4 quarters ($2/0.5 = 4$). Seasonal factors therefore generate a peak in the spectrum at 0.5π . Similarly, a frequency of 0.2π implies a periodicity of $2/0.2$ or 10 quarters.

The coherence and the gain are high at low frequencies and drop at the frequency of 0.2π . At frequency zero the coherence approaches unity, meaning that in the long run money growth explains inflation almost completely. The bootstrapped confidence bounds indicate that neither the gain nor the coherence are significantly different from unity at frequency zero.²² Interestingly, the coherence is also high at a frequency of 0.3π , that is, corresponding to a periodicity of 6 quarters. At higher frequencies, however, gain and coherence fluctuate. When controlling for output growth and the change in the interest rate, the gain and the coherence at frequency zero increase, while the confidence intervals become narrower.

Figure 5 shows the results from cross-spectral analysis of inflation and the output gap. Here, the coherence is high at business cycle frequencies of 0.05π to 0.2π , which correspond to a frequency of 40 to 10 quarters. In contrast to the cross-spectral evidence for money growth and inflation, the gain (and to a lesser extent also the coherence) do not show a maximum at

²⁰ While we elsewhere in the paper let π denote the rate of inflation, in discussing frequencies we let it denote the irrational number defined by the ratio of the circumference of a circle to its diameter.

²¹ Since ω is measured in cycles per period, the smallest cycle distinguishable in quarterly data is one cycle every two periods, which is also called the Nyquist frequency.

²² The bootstrap procedure follows Berkowitz and Diebold (1998). To obtain the confidence bands, 1000 replications have been performed.

the zero frequency. The partial cross-spectrum, controlling for money growth and the change in the interest rate, shows almost the same pattern as the full spectrum.

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:

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

where $\hat{f}_{xx}(\omega)$ 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 model by a $T \times T$ (T being the sample size) matrix A with unity on the diagonal for each included frequency and zero elsewhere,

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

with an asterisk, “*”, denoting the complex conjugate of the transposed matrix. In other words, to compute β 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 while it 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

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

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 component $T - k$.

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:

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

where i is either the high-frequency (*HF*) or low-frequency (*LF*) band ($i = HF, LF$). As implied by the empirical model discussed above, we expect that money and output growth have an impact on inflation at low frequencies, and the output gap at high frequencies.

Table 2 shows the results for the band spectrum regressions at different frequency bands. 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 enter with significant coefficients, whereas the interest rate change and output growth are insignificant. The coefficient on money growth, however, is far away 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 test statistic of $F_{2,137} = 333.3$ and 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 2 show the results for the low-frequency regression. Money growth is highly significant at low frequencies. The coefficient increases as the band excludes higher

frequencies, but remains significantly below unity. Output growth is significant only when the low frequency is defined as periodicities of more than eight years and the coefficient is then significantly above -1, the theoretically expected value. Surprisingly, the interest rate change is never significant. 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 a p-value of zero, irrespectively of whether we draw the distinction between high and low frequency at two, four or eight years with (test-statistics of $F_{2,31} = 121.1$ $F_{2,13} = 69.9$ and $F_{2,4} = 90.2$, respectively).

The last three columns of Table 2 present the results of the band spectrum regression for high frequencies. Money growth and the interest rate change are always insignificant with coefficients close to zero. The output gap is significant when the band includes frequencies up to four or eight years. This could mean that the highest frequencies of the output gap contain considerable noise that is not helpful for explaining inflation.

Next, we test if the relation between inflation, money growth and output growth differs significantly across frequencies. An F-test of the hypothesis that the low- and high-frequency coefficients are equal gives a test statistic of $F_{3,135} = 5.00$ for a split at the two-year frequency, $F_{3,135} = 10.34$ for a split at the four-year frequency and $F_{3,135} = 36.08$ for a split at the eight-year frequency against a 5% critical value of 2.67. We thus find strong evidence for the notion that inflation is associated closely with money growth at low, but not at high, frequencies.

As noted above, the parameter on money growth, while significant, is much below unity.²⁵ Moreover, the coefficient on output growth is insignificant and above minus unity. 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:

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

where we think of $\varepsilon_t^{LF,y}$ 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 This part follows Gerlach (1995).

$$(9) \quad \alpha_\mu = 1 + \alpha_v (X_1' X_1)^{-1} X_1' X_2,$$

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 2. With the correction for the omitted variable bias we see that now for all frequency bands the coefficients on money growth are close to the theoretically expected value of 1, whereas the coefficient on output growth is between -0.70 and -1.04.

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 changes in interest rates do not fully control for shocks to velocity. Reynard (2005) demonstrates that unless shifts to velocity induced by disinflation are controlled for, US and euro area data will incorrectly suggest that there is no proportional effect from money growth to inflation in recent decades.

5.2 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 with headline inflation as the dependent variable, and include the output gap and the low-frequency components of money growth, output growth and the interest rate change as the explanatory variables. Our final inflation equation, which Gerlach (2003, 2004) refers to as “two-pillar Phillips curve”, is thus:

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

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 3. 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 output gap at all frequencies, except that we lag money growth by 12 quarters to account for the lag in transmission from money to prices. 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 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 3 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.²⁶ Again, the first column shows the results for a model that is estimated on lagged money growth, output growth, the interest rate change and the output gap at all frequencies, while the next three columns include only the low-frequency component of the other regressors. In general, the use of the Hannan estimator leads to results very similar to those above. Of course, since the variables are filtered to handle the serial correlation in the residuals, the adjusted R^2 's 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 3. 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.

²⁶ 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.

In sum, the regression results reported in Table 3 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.

6. Causality between money growth and inflation

While our results indicate that money growth lagged three years is strongly correlated with current inflation, we have not directly tested the hypothesis that low-frequency movements in money growth contain information which is useful for predicting future inflation that is not yet embedded in past inflation. Galí (2003) argues that while the existence of a stable money demand function suggests that inflation and money growth are related, that does not imply that money growth causes 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.²⁷

The frequency-wise measure of causality is based on a bivariate vector autoregression (VAR) containing the variables of interest, in our case inflation and money growth.²⁸ The starting point is the moving average representation of the system,

$$(10) \quad \begin{bmatrix} \pi_t \\ \mu_t \end{bmatrix} = \begin{bmatrix} \Psi_{11}(L) & \Psi_{12}(L) \\ \Psi_{21}(L) & \Psi_{22}(L) \end{bmatrix} \begin{bmatrix} \eta_{1t} \\ \eta_{2t} \end{bmatrix}$$

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.²⁹ Money growth Granger-causes inflation if $\Psi_{12}(L)$ is non-zero. The frequency-wise measure of causality suggested by Geweke (1982) and Hosoya (1991) is defined as:

²⁷ 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.

²⁸ See also Granger and Lin (1995) and Breitung and Candelon (2005).

²⁹ 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.

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

This measure is zero if $|\Psi_{12}(e^{-i\omega})| = 0$, which implies that μ_t does not cause π_t . In assessing causality it is important to account for possible feedback from other variables to the variables of interest. In this case, it is necessary to base the causality measure in equation (11) on the partial periodograms and cross periodograms by conditioning on the information contained in the other variables.³⁰ Since the causal relation between money and inflation could be influenced by the output gap and interest rate changes, we condition our causality tests on these two variables. Instead of measuring causality between π_t and μ_t directly, we compute the causality measure for the projection residuals u_t and v_t , which are obtained by regressing money growth and inflation on the residuals from a regression of the output gap and the interest rate change on lagged values of π_t and μ_t .³¹ Hosoya (2001) shows that the causality measure from money growth to inflation, given the output gap and the interest rate change, is equal to the bivariate causality measure between these projection residuals u_t and v_t .

For causality tests the lag length should neither be too short – since this possibly cuts off some significant coefficients – nor too large since in this case the tests may lack power. We perform the tests with a lag length of six. We compute the moving average (MA) representation of the VAR and apply a Fourier transformation to the resulting MA coefficients. Breitung and Candelon (2005) show that the hypothesis $M_{\mu \rightarrow \pi}(\omega) = 0$ 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 6 shows the causality measure over frequencies from zero to π . We find significant causality from money growth to inflation at low frequencies. At frequencies above 0.4π , which corresponds to five quarters, no significant causality is found. 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

³⁰ See Hosoya (2001) and Breitung and Candelon (2005).

³¹ In this regression we include the contemporaneous values of inflation and money growth, since Hosoya (2001) argues that omitting them may lead to a finding of spurious causality. Excluding π_t and μ_t , however, does not alter the results.

inflation shows a clear peak at the business cycle frequency of 10 quarters. We thus find that output gaps predict inflation at higher frequencies than money growth. However, the test indicates causality from inflation to the output gap at very low frequencies, which is surprising since the output gap has little variation in this frequency band, and at frequencies of six and three quarters, which may well be spurious. Moreover, we note that while the first three causal measures are robust to the choice of lag length in the regression, the fourth is not. Overall, we are therefore somewhat dubious about the economic significance of the finding that inflation causes the output gap at very high and low frequencies.

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 1970-2005. 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 to the output gap, which underlies both the ECB's two-pillar framework and the SNB monetary policy concept, 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 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 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 impacts on, and causes, inflation. This suggests 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 concept has served to clarify that monetary aggregates, while important, are not the only information variables relied on.

Overall, we interpret the results as providing 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. However, the results are preliminary and several extensions appear warranted. In particular, it would be desirable to compare the information content of M2 versus M3. Though Gerlach-Kristen (2005) 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, short-term 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. These extensions we leave for future research.

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Tables and Figures

Table 1. Unit root tests

Sample period: 1970Q1 to 2005Q2.

	<i>ADF</i>	<i>PP</i>	<i>ERS</i>	<i>KPSS</i>	<i>SIC lag</i>
Inflation	-2.35	-3.84*	-1.97*	2.04*	2
Money growth	-3.81*	-4.75*	-3.78*	2.39*	1
Output growth	-6.95*	-10.92*	-1.47	0.05	1
Output gap	-3.62*	-3.14*	-3.58*	0.10	2
Interest rate change	-7.06*	-8.62*	-5.63*	0.06	1

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% critical values are -2.89 for the Augmented Dickey-Fuller (ADF) and the Phillips-Perron (PP) test, -1.95 for the Elliot, Stock and Rotenberg (ERS) test and 0.46 for the Kwiatkowski, Phillips, Schmidt and Shin (KPSS) test. An asterisk, “*”, indicates the rejection of the null hypothesis at the 5% level.

Table 2. Band spectrum regressions

$$\text{Estimates of } \pi_t^i = \alpha_0^i + \alpha_g^i g_t^i + \alpha_\mu^i \mu_t^i + \alpha_\rho^i \rho_t^i + \alpha_\gamma^{LF} \gamma_t^{LF} + \varepsilon_t^i$$

Sample period: 1970Q1 to 2005Q2.

	<i>0.5 to ∞ years</i>	<i>2 to ∞ years</i>	<i>4 to ∞ years</i>	<i>8 to ∞ years</i>	<i>0.5 to 2 years</i>	<i>0.5 to 4 years</i>	<i>0.5 to 8 years</i>
Money growth	0.26** (0.05)	0.31** (0.05)	0.39** (0.04)	0.67** (0.05)	0.03 (0.06)	0.01 (0.04)	-0.02 (0.03)
Output growth	0.04 (0.08)	0.02 (0.04)	-0.02 (0.04)	-0.02* (0.01)			
Interest rate change	0.02 (0.25)	-0.13 (0.45)	-0.36 (0.55)	0.08 (0.60)	0.21 (0.12)	0.16 (0.12)	0.18 (0.16)
Output gap (<i>t</i> -1)	0.23** (0.04)	0.25** (0.03)	0.29** (0.03)	0.34** (0.02)	0.04 (0.03)	0.08** (0.03)	0.11** (0.02)
\bar{R}^2	0.43	0.57	0.65	0.86	0.002	0.03	0.18
Degrees of freedom	137	31	13	4	103	121	130
Money growth (bias corr.)	0.88	0.95	0.91	0.98	0.78	0.84	0.83
Output growth (bias corr.)	-0.98	-1.04	-0.94	-0.70			

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 3. Two-pillar Phillips curve

$$\text{Estimates of } \pi_t = \beta_0 + \beta_g g_t + \beta_\mu \mu_{t-12}^{LF} + \beta_\rho \rho_t^{LF} + \beta_\gamma \gamma_t^{LF} + \varepsilon_t$$

Sample period: 1970Q2 to 2005Q2.

Approach to control for serial correlation in the residuals:	<i>0.5 to ∞</i>	<i>Filtered</i>	<i>Filtered</i>	<i>Filtered</i>	<i>0.5 to ∞</i>	<i>Filtered</i>	<i>Filtered</i>	<i>Filtered</i>
	<i>years</i>	<i>2 to ∞</i>	<i>4 to ∞</i>	<i>8 to ∞</i>	<i>years</i>	<i>2 to ∞</i>	<i>4 to ∞</i>	<i>8 to ∞</i>
	Newey-West standard errors				Hannan's efficient estimator			
Money growth (<i>t</i> -12)	0.26** (0.06)	0.41** (0.06)	0.49** (0.06)	0.68** (0.06)	0.08 (0.05)	0.31** (0.08)	0.49** (0.09)	0.68** (0.07)
Output growth	0.07 (0.07)	0.21 (0.11)	0.13 (0.13)	0.24 (0.18)	0.07* (0.03)	0.15 (0.12)	0.10 (0.16)	0.22 (0.22)
Interest rate change	0.03 (0.25)	-0.51 (0.47)	-0.93 (0.71)	-4.47** (1.19)	0.13 (0.13)	-0.16 (0.45)	0.40 (0.71)	-4.07** (1.55)
Output gap (<i>t</i> -1)	0.17** (0.03)	0.16** (0.02)	0.16** (0.02)	0.17** (0.02)	0.15** (0.02)	0.13** (0.03)	0.12** (0.03)	0.15** (0.02)
\bar{R}^2	0.45	0.54	0.59	0.67	0.33	0.26	0.33	0.54
Durbin-Watson	1.12	1.10	1.19	1.47	1.91	2.04	2.02	2.03

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.

Table 3 (cont.). Two-pillar Phillips curve

$$\text{Estimates of } \pi_t = \beta_0 + \beta_g g_t + \beta_\mu \mu_{t-12}^{LF} + \beta_\rho \rho_t^{LF} + \beta_\gamma \gamma_t^{LF} + \varepsilon_t$$

Sample period: 1970Q2 to 2005Q2.

	<i>0.5 to ∞ years</i>	<i>Filtered 2 to ∞ years</i>	<i>Filtered 4 to ∞ years</i>	<i>Filtered 8 to ∞ years</i>
Approach to control for serial correlation in the residuals:	Allowing for lagged dependent variable			
Money growth (<i>t</i> -12)	0.09 (0.05)	0.22** (0.05)	0.29** (0.06)	0.49** (0.08)
Output growth	0.05 (0.04)	0.17* (0.20)	0.14 (0.09)	0.24 (0.15)
Interest rate change	0.13 (0.18)	-0.23 (0.32)	-0.48 (0.46)	-3.24** (1.07)
Output gap (<i>t</i> -1)	0.08** (0.02)	0.09** (0.02)	0.10** (0.02)	0.12** (0.02)
Lagged inflation	0.56** (0.07)	0.47** (0.07)	0.41** (0.08)	0.28** (0.08)
\bar{R}^2	0.61	0.65	0.66	0.69
Durbin-Watson	2.22	2.15	2.07	2.03

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

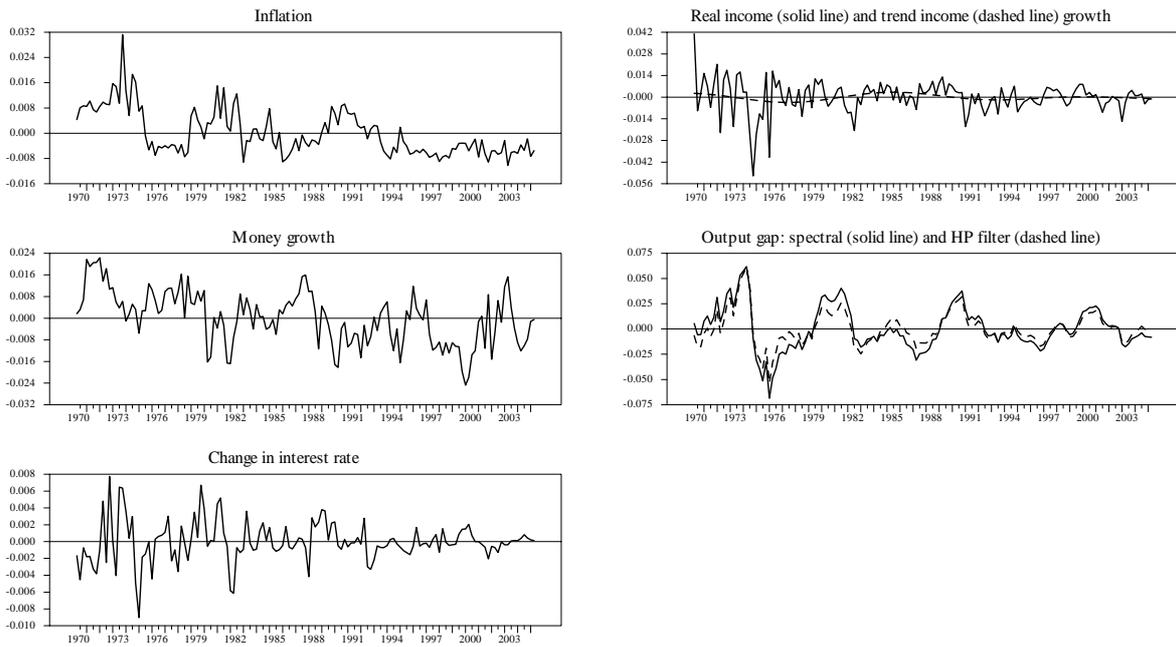


Figure 2. Inflation and money growth at low and high frequency

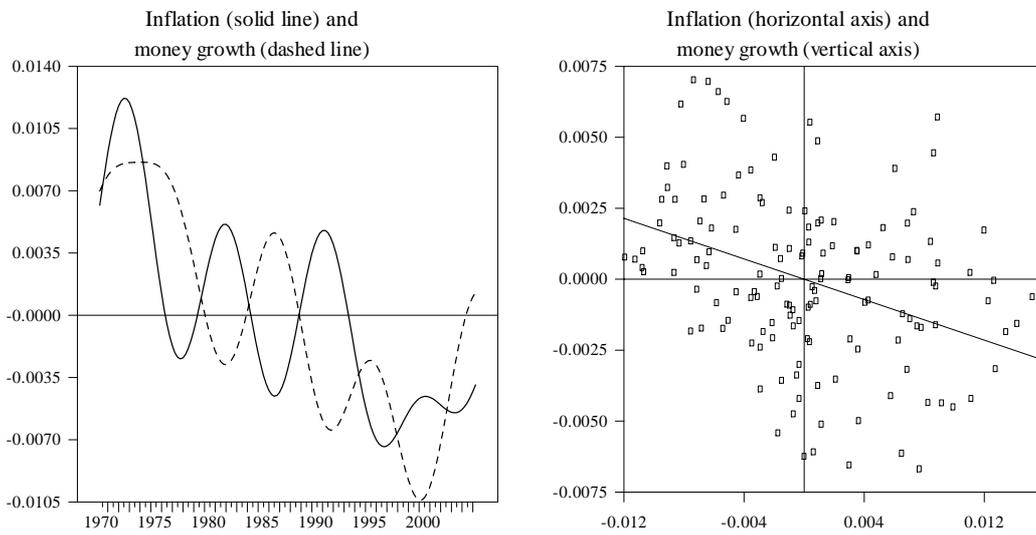


Figure 3. Inflation and output gap at low and high frequency

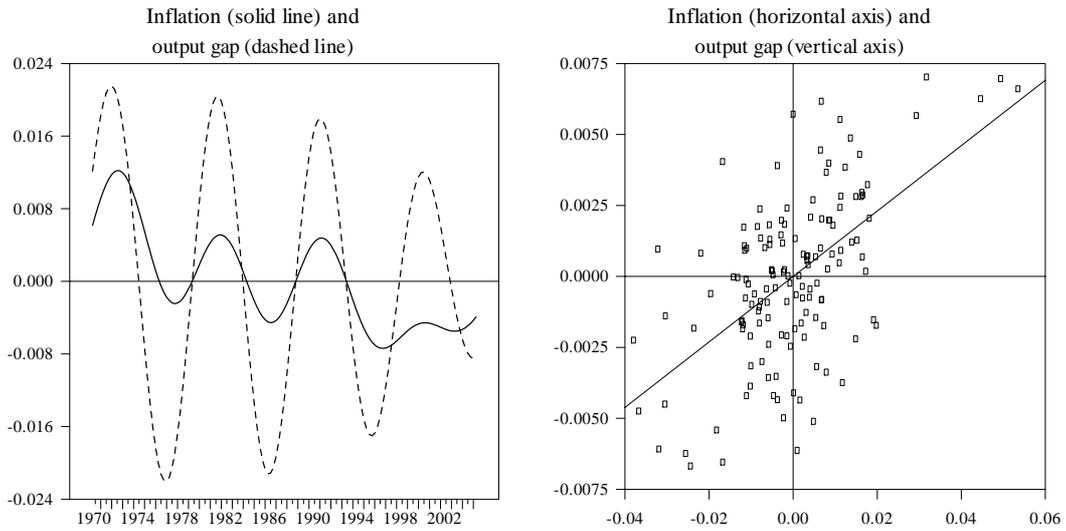
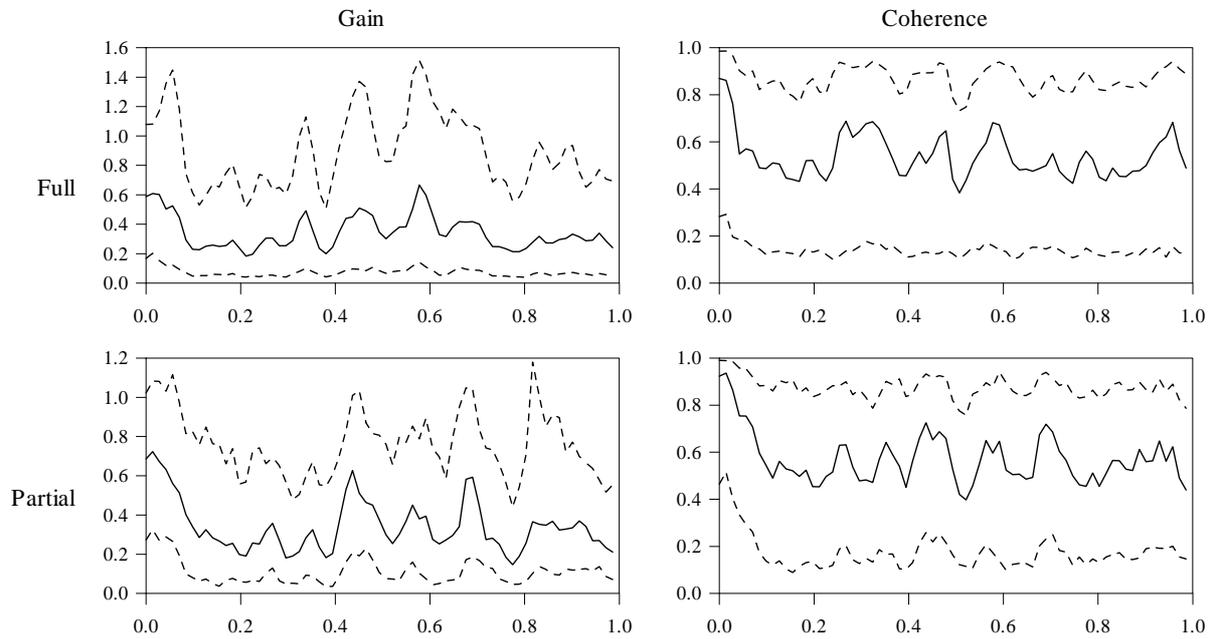
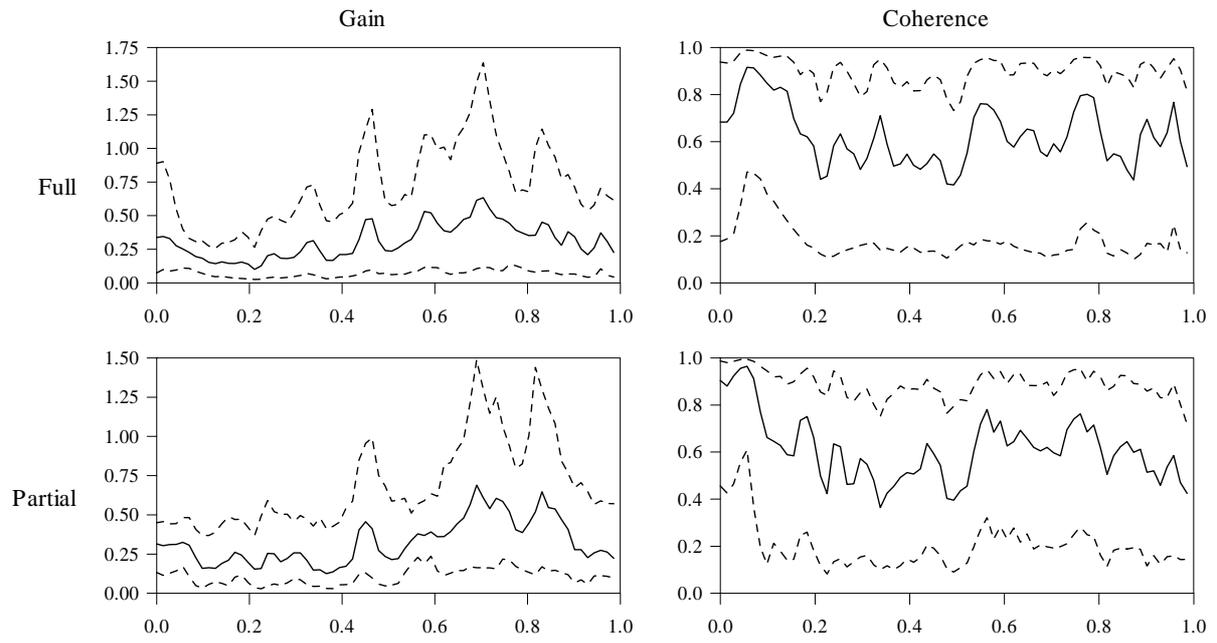


Figure 4. Cross-spectrum of inflation and money growth



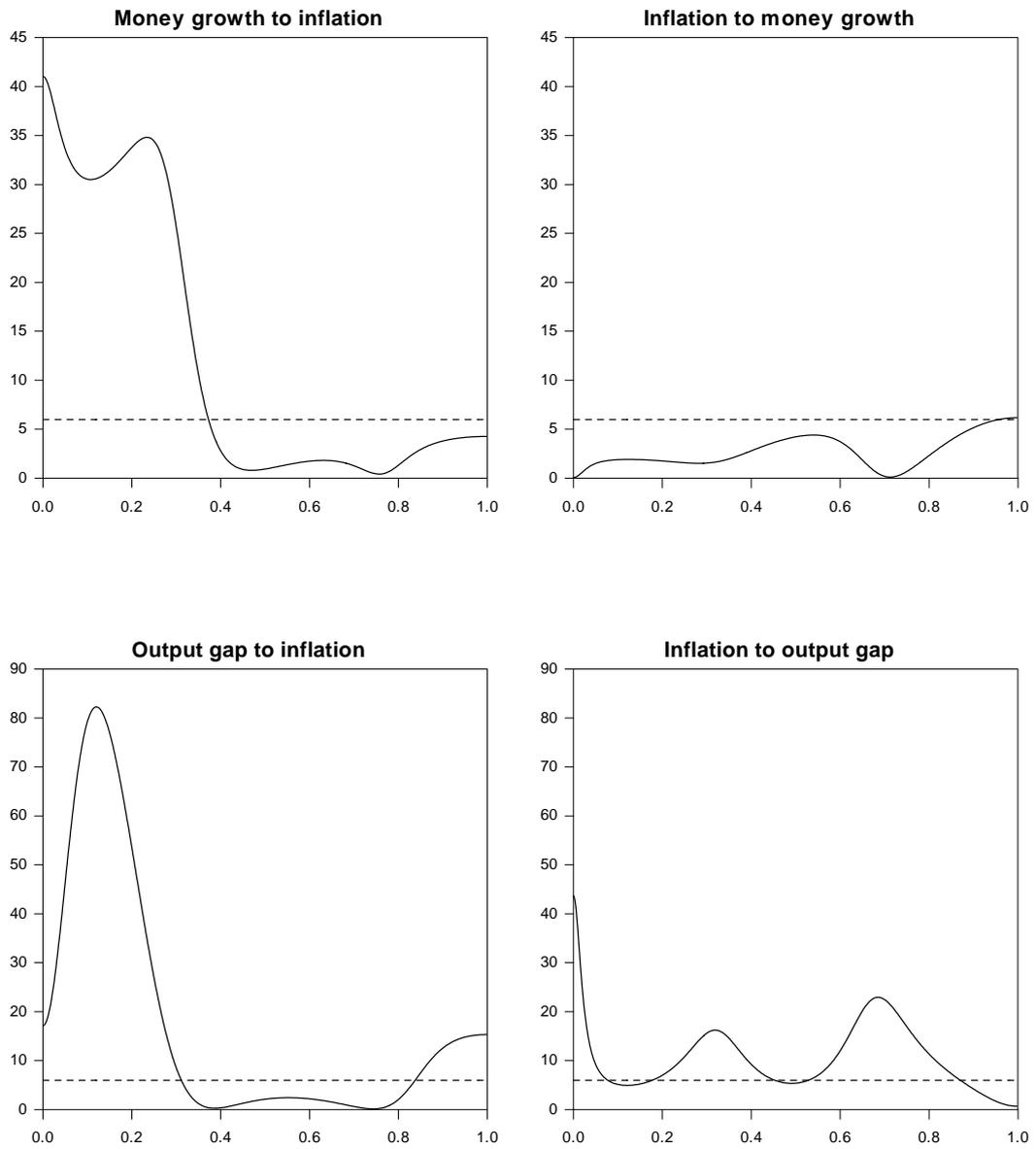
Note: The horizontal axis shows the frequency ordinates as fractions of π . The dashed lines show bootstrapped 95% confidence bounds.

Figure 5. Cross-spectral analysis of inflation and the output gap



Note: The horizontal axis shows the frequency ordinates as fractions of π . The dashed lines show bootstrapped 95% confidence bounds.

Figure 6. Causality



Note: The horizontal axis shows the frequency ordinates as fractions of π .