

THREE ESSAYS ON MONETARY POLICY IN THE UK

by

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Abstract

The dissertation studies monetary policy in the UK and specifically three topics: the monetary policy reaction function of the Bank of England, the influence of QE on nominal income and the determination of inflation and the role of money in it.

In the study of the reaction function of the Bank of England in chapter 2 (which draws on Cobham and Kang, 2012a), there are two issues involved a comparison of two different approaches: the GMM approach and the ex ante forecast approach. The first issue is the time horizons for inflation and the output gap. The estimations using the GMM method indicate that the best fit is for inflation one year ahead and for the output gap one quarter ahead. The estimations in the ex ante forecast approach indicate the best fit should be for inflation two years ahead and output growth one quarter ahead, which is closer to the Bank of England's view. The second issue is about the smoothing behaviour in interest rate decisions. The GMM method suggests smoothing behaviour incorporated in a lagged dependent variable while the ex ante forecast method suggests no smoothing since the lagged change of the interest rate is not significant in the regression. The latter suggestion is also closer to former policy makers' views. In addition, the GMM method may suffer from a weak instruments problem and the ex ante forecast approach is a better method to estimate the monetary policy reaction function. I also try to apply the ex ante forecast approach to the reaction function of the European Central Bank, with results which are less precise but still closer to what the ECB claims to do.

The third and the fourth chapters address the monetary aggregates, which have been ignored in monetary policy research for a long time but fluctuated strongly during the financial crisis period and after QE was implemented. What's more, while most work in recent years focuses on the fluctuations in financial markets, the dissertation discusses the influence of the crisis and QE on macroeconomic activity. In chapter 3 (which draws on Cobham and Kang, 2012b), a flow of funds matrix is used to illustrate the monetary developments. This is followed by regressions of a naïve ad hoc reduced form model which considers the growth of nominal spending as determined by the growth of

nominal money and other variables. The results of the regression suggest that money has had a bigger role since the crisis and under QE. Then various counterfactual assumptions about money growth are made and the counterfactual paths of nominal spending are calculated by using the estimated parameters of the regression above. The comparison of those counterfactuals indicates that QE has had a considerable influence on nominal spending. In the fourth chapter, money growth is studied in a long-run perspective, in terms of its relation with inflation. In a reduced-form Phillips curve, inflation is explained by variables at different frequencies. The money growth, GDP growth and interest rate change which are included in the Quantity Theory of Money are expected to link inflation at low frequency while the output gap as well as exchange rate and import price has a relation with inflation at high frequency. The frequency-domain technique is used in this process. The estimated results suggest money has a relationship with inflation only at low frequency while the output gap, on the other hand, relates inflation at high frequency. Then regressions on low frequency and high frequency are also run. Frequency-wise causality measures follow to support the indications. From the results given by the third and fourth chapters, it is suggested that it is the time to pay attention to money again in monetary policy research. And it would be useful to incorporate money or credit into wider macroeconomic models of the UK economy.

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Chapter 1. Introduction

When inflation targeting was introduced in the 1990s by central banks in the main developed countries, formally or informally, the monetary policy frameworks in these areas started to change towards a single type with identical characteristics, under which the inflation rate was brought for nearly twenty years to a lower and more stable level than under previous monetary policy frameworks. The common factors in these monetary policy frameworks include the aim of monetary policy, the instrument used, the reaction function, the independence of the central bank and so on. Table 1.1 provides a comparison of the monetary policy frameworks of the Federal Reserve (FR), the Bank of England (BoE) and the European Central Bank (ECB) from several aspects. These similar arrangements in the table consist of a new type of framework that involved a clear precommitment and improved the central banks' credibility, which helped to lower the inflation expectations of the private sector and helped to stabilize inflation.

The Bank of England embarked on this new framework after UK's exit from the European Exchange Rate Mechanism (ERM) in September of 1992, and the framework was then enhanced in 1997 when the independence of BoE was increased. The first innovation of the new monetary policy framework¹ was to change the policy target to an inflation target—an initial range of 1%-4% on the RPIX (retail prices index excluding mortgage interest payments) but 2.5% by the end of the Parliament (i.e. 1997), and this was continued as 2.5% of RPIX in 1997. Under the new arrangements the Bank's goal was formally stated as to “*maintain price stability and subject to that objective, to support the government's economic policy, including its objectives for growth and employment*”. (BEQB, 1998(2): 93).² Inflation targeting, compared to other targets in the UK's history, has a better performance in stabilising demand shocks and influencing inflation expectations, under a simple analysis using the AD-AS model. (See Cobham, 2002, p.8 and table 1.1). And the publication of inflation forecasts in the *Inflation Report*, which was another important feature in the new framework, helped to rescue the credibility of monetary policy from the low point it reached on Black Wednesday. The *Inflation Report*, first published in 1993, originally included the ‘central projection’ of

¹ There are some differences between the policy framework at 1993 and that from 1997: the BoE became operationally independent in 1997; the members of the MPC became individually accountable in 1997; the objective of inflation became 2.5% rather than a range; and the published forecasts began to include the variance and skews. Though the new framework was in some sense completed only in 1997, inflation targeting started in 1993 and the transparency and accountability improved a lot from then, I include the period during 93 and 97 in the new framework period.

² BEQB is short for *Bank of England Quarterly Bulletin*

inflation over the next two years with a range either side but this was replaced by a ‘fan chart’ in 1996. The ‘fan chart’ shows a central band indicating the central projection with 10% probability that inflation would fall in this band and also shows further bands in which inflation would fall with a chance of 20%, 30%, etc. (BEQB, 1996a: 46-8) The information contained in this publication was intended to enhance the transparency and openness of the monetary policy, in order to help the private sector understand the intentions of the central bank better and to lower inflation expectations. The reputation of monetary policy and the credibility of the central bank started to improve. Especially, the increased independence of the Bank of England from 1997 made that reputation better and made the policy more time-consistent.³ Another characteristic of the new framework is that the role of interest rate in influencing the economy was enhanced, or at least clarified. Though information on other variables including the monetary aggregates is still mentioned in the Inflation Report, the policy makers focus on making decisions on the bank rate or the repo rate. Under the popular New Keynesian model, it is the change in interest rate that can affect spending and investing decisions and thus affect aggregate demand. Given the inflation target set by the Chancellor, the Monetary Policy Committee (MPC) in the central bank is responsible for interest rate adjustment to maintain price stability. In Kohn (2001), the work on interest rate decision making was described. The latest data have to be collected and analyzed before the MPC’s monthly meetings and the information is used in the MPC’s discussion. Every member has his own views about the central forecasts on the economic activity based on the current analysis and various models. They vote for a particular proposition and the published record shows their attitude to the interest rate decision, whether they prefer a rise, no change or a decrease in the current interest rate.

Under this monetary policy framework, the outcome for economic activity in UK improved since 1993 and has been more satisfactory after 1997 than in previous periods. Figure 1.1 shows the inflation and GDP growth rate.⁴ The annual growth rate of RPIX had been in the range of 5% to 20% and it was highly variable between 1976 and 1983, and that was followed by a relatively steady period of around 5% inflation until 1989. There was another peak at the end of 1990 at 9.3% and inflation was at 4.3% in the third quarter of 1992 when the UK stopped fixing its exchange rate. Inflation fell

³ Before the independence of the BoE, the disagreements between the Chancellor and the Governor on interest rate decision may have led the private sector to have less confidence and may have harmed credibility. See King (BEQB,1999c:297). See also Chadha, Macmillan and Nolan (2006).

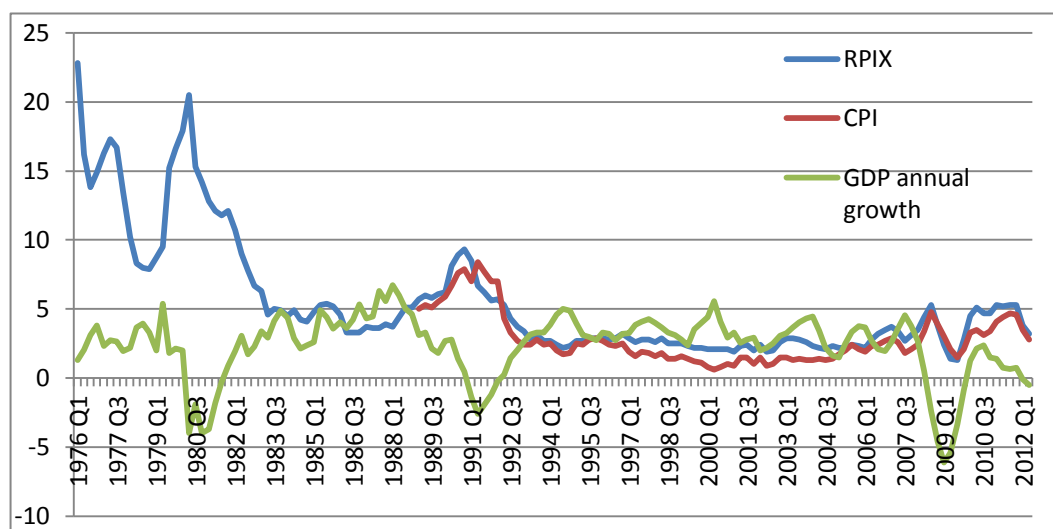
⁴ The BoE changed its inflation measure from RPIX to CPI in 2004. Thus I put both series in the figure.

continuously once inflation targeting started and remained below 3% up to 2007. The annual growth rate of the CPI, which is only available since 1988, shows a similar trend. It peaked in 1991 and declined afterwards to 2.7% in 1992 Q4 and then stayed around 2% from 1994. Both RPIX and CPI show that inflation was controlled under the new monetary policy framework at a lower level than in previous periods. And it has also been more stable. However, inflation began to fluctuate again from 2008 and reached 4.8% on the CPI in the autumn of 2008. Then it decreased to 1.5% one year later but started to pick up again in 2010. Inflation during the crisis period has been variable. On the other hand, GDP growth shows three low points in the whole period. The first happened in 1980/81 and the second was in 1990/91. GDP growth increased from a negative value in 1991 to 4.8% in 1994 and then varied around 3.5% until 2007. The third trough in the figure started from 2008 Q3 and GDP growth did not return to a positive level until 2010 Q1. After that, the GDP growth kept on increasing slightly to 2.4% in 2010Q3 and then dropped again, particularly since 2011Q2. It maintained negative in 2012. Despite the unusual performance in the crisis period, inflation and GDP from 1993 have been kept at desirable levels and with low variability.

Table 1.1 The frameworks of the monetary policy

	The ECB	The FRB	The BoE
Targets	Price stability (inflation below, and now close to, 2% on HICP)	Informal inflation targeting and unemployment	Formal inflation targeting of 2% on CPI
Policy rates	Refinancing rate	Federal fund rate	Bank rate
Independence	highest	high	Instrument but not policy
Forecasts	Staff forecasts only for the calendar year	Staff forecasts but is published with a lag of 5 years	Published every quarter (in Inflation Report)
Monetary reference value	Yes, but status unclear	No	No

Figure 1.1 RPIX, CPI and GDP growth



When assessing the monetary policy of a central bank, a core question is how the instrument is adjusted by the policy makers in response to the development of the economy (Svensson, 1999). The study of this question is often undertaken mainly through an analysis of the reaction function of the central bank, which shows the monetary authorities' response to the deviation of variables from target or trend. When central banks focus on using interest rates to target inflation, it is popular to estimate the reaction function by a Taylor Rule. In Taylor (1993), the interest rate responds to the deviation of inflation from its target level and to the current output gap, and Taylor proposed this specific rule with specific coefficients. The interest rates implied by this rule were quite similar to those set by the Federal Reserve over the period 1987-92 (Taylor 1993:204, Figure 1). Many economists have estimated a reaction function of that form, in order to obtain estimates of the coefficients for other central banks. Among these empirical studies, some found the exchange rate was also significant in the reaction function, which means some central banks respond to the exchange rate as well. Some studies show central banks responding to the monetary growth rate also. One particular specification which has been widely implemented is the 'forward-looking specification'. Here central banks do not respond to the current deviation of inflation from target, as originally proposed in Taylor (1993), but to the expectation of that in the future. In other words, if the policy makers are deciding whether they should change the interest rate this month, they generally consider the inflation and output at some future date, for example the levels expected in one year's time.

For the new monetary policy framework used in the Bank of England since 1997, one

could use the Taylor rule to estimate the reaction function, at least for the period between the ‘independence’ of the BoE in 1997 and the crisis in 2008. As there are several empirical studies which estimate the reaction function of the BoE for the period between 1980 and 2000 (Table 2.1 in Chapter 2), I put my attention on two specific issues when considering the period 1997 to 2007. The first issue relates to the time horizon of forward-looking variables: how long should the leads on inflation and output be? The Bank of England claimed on their website that “*the maximum effect on output is estimated to take up to about one year. And the maximum impact of a change in interest rates on consumer price inflation takes up to about two years*”.⁵ But most empirical estimates of the reaction function have used a horizon of one year on inflation and a horizon of zero on output. The second issue is about interest rate smoothing: the approach used in the previous literature put a lagged interest rate into the regression and interpreted its significance as evidence of interest rate smoothing. However, this conclusion is doubted by some former members of the MPC in the BoE (e.g. Goodhart, 2005). Whether the Bank of England smoothed the interest rate and what is the ‘proper’ definition of interest rate smoothing will be discussed in the thesis.

Chapter 2 of this dissertation focuses on the two issues above by estimating the monetary policy reaction function of the Bank of England by two forward-looking approaches: the conventional GMM approach and the ex-ante forecast method developed by Goodhart (2005). In each case the horizons for inflation and output are varied to find the best fit. It turns out that for the standard GMM approach the best fit occurs for inflation four quarters ahead and the output gap one quarter ahead, while the best fit for the ex ante forecast approach is with inflation eight quarters ahead and output growth one quarter ahead. The latter horizons are much closer to what is implied by the Bank’s views on the transmission mechanism. In addition the standard GMM approach requires a lagged dependent variable which implies an implausibly slow adjustment of the policy interest rate to an inflation shock, while in the ex ante forecast approach there is no need for a lagged term in the change in policy rate. The standard GMM approach also suffers from a weak instruments problem. In the light of these findings it is argued that the ex-ante forecast approach is the better way to estimate the monetary policy reaction function.

In the last section of Chapter 2, the ex-ante forecast approach is applied to the

⁵ <http://www.bankofengland.co.uk/monetarypolicy/Pages/how.aspx>

estimation of the reaction function of the ECB. As it is impossible to calculate the ‘ex-ante projections’ for the ECB from the data available, I have used the projections in the ECB’s Survey of Professional Forecasters (SPF) as a proxy for the ECB’s own forecasts. And I consider different timings of interest rate in running the estimation. None of the results supports the identification of the horizons in the estimation of reaction function as 4 quarters for inflation and zero quarters for output. The preferred result indicates the coefficient of deviation of the inflation projection from target should be around 1, which is similar to what I got in the BoE case.

After the key policy rates had reached their lower bounds in 2008-9, both in the US and the UK, their central banks each started to implement unconventional policy in response to the worsening financial crisis. This unconventional monetary policy, under which the central banks purchase large amounts of securities from the private sector by increasing the reserves of the banks, is called ‘Quantitative Easing’ (QE). The Federal Reserve began its ‘Large-Scale Asset Purchases’ (LSAP) from November 2008 and had purchased US\$1.75 trillion assets in total by March 2010. The Bank of England announced it would implement QE in March 2009 and completed it with £200 billion in 2010 Q1.

The purpose of QE as claimed by the Bank of England is “*to inject money directly into the economy in order to boost nominal demand. Despite this different means of implementing monetary policy, the objective remained unchanged - to meet the inflation target of 2 per cent on the CPI measure of consumer prices.*”,⁶ in which money is emphasized again twenty years after the abandonment of monetary targets by the Bank of England. In the monetary policy framework I described at the beginning, it is interest rates which policy makers use to hit the inflation target not money. Though the data on the monetary aggregates is reported in the *Inflation Report*, this is only as an indicator not a policy instrument. And in most studies of the reaction function in the last twenty years,⁷ the monetary aggregates were not even used as instruments in forming inflation projections. It seems that the monetary aggregates have been ignored in monetary policy research during the tranquil time of the Great Moderation. Now the Bank of England has at least in part come back to the monetary aggregates when the financial crisis had led to very low inflation forecasts and the interest rate was at the effective lower bound

⁶ <http://www.bankofengland.co.uk/monetarypolicy/Pages/qe/default.aspx>

⁷ Those works are the papers using the GMM approach which I discuss in Chapter 2.

(ELB). However, in contrast to the earlier monetary targeting policy, the objective after the crisis remains unchanged, which is “*to meet the inflation target of 2 per cent on the CPI measure of consumer prices*”. It is clear that the conduct of QE is not a replacement of the monetary policy strategy in the pre-crisis period but a supplement to it. QE brought about an injection of £200 billion into the economy and this exogenous shock arguably gave money supply a causal role in macroeconomic activity. Under the BoE’s aim of “*boosting the supply of money and credit and thus raising the rate of growth of nominal spending to a level consistent with meeting the inflation target in the medium term*”,⁸ the latter part of the dissertation consists of studies of money’s role in monetary policy after the crisis – how money affects output in the medium term and inflation in the long run. Unlike other work on QE, my study does not emphasize money’s influence on financial markets but focuses on its direct effect on macroeconomic activity.

Chapter 3 emphasizes the effect of QE on medium-term output, as announced by the BoE when QE started. At the beginning of this chapter, I do a simple SVAR analysis in line with other research, in order to estimate the impact of QE. Instead of using spreads in the model, I interpret the QE shock as an increase in broad money. This attempt at SVAR analysis produces similar results to studies that have included financial market variables in their SVAR models. Then in order to show monetary developments under QE, I use a flow of funds matrix to argue that the financial crisis and QE have constituted exogenous shocks to money and credit which could not be absorbed immediately. I also present a reduced form regression which treats the growth of nominal spending as determined by the growth rate of nominal money and other variables. The results suggest that money growth may not be important in the pre-crisis period but have a larger role in the period of crisis and QE. By using the parameters from the estimation, I create four counterfactual scenarios which consider the effects of QE under different assumptions about the offsets, in order to illustrate the impact of crisis and QE. The estimates of the impact under this method are a bit larger than what the SVAR models suggest but quite close. The results in this chapter suggest that in the medium term monetary aggregates have some influence on output. And even without detailed analysis through the financial markets, we can still get information from the development of money about the movements in the UK economy.

⁸ Press statement 5 March 2009, available at <http://www.bankofengland.co.uk/publications/news/2009/019.htm>

Chapter 4 illustrates inflation determination and money's role in it in the long run. Because the Bank of England looks at inflation and nominal spending in the medium run as well as inflation in the long run, it will help us understand QE better by studying the relationship between money and inflation in the long run. In this chapter, a Phillips-Curve regression is estimated. The regressors include the standard Quantity Theory variables, the output gap and two cost-push variables. Inflation, as well as other variables, is decomposed into components of different frequencies by the frequency-domain technique. The results indicate that money has a long-run impact in inflation determination. Particularly, when the crisis/QE period is taken into consideration, the coefficient on money is larger. On the other hand, in the medium term, money is not significant in the regression no matter whether the crisis/QE period is included or not. And it is the output gap which has a significant role in determining inflation, as well as exchange rate in short-term. This evidence suggests that money can influence inflation in the long run directly and it should not be ignored when people analyze monetary policy strategy. In the short run, the shocks to money may not have effects immediately on inflation directly but they will do so indirectly if changes in money can affect the output gap.

Chapter 2. Time Horizons and Smoothing in Reaction Function

2.1. Introduction

In this chapter I focus on two particular issues in the estimation of a monetary policy reaction function, for the case of the Bank of England. The first issue concerns the time horizon of the forward-looking variables in the regressions, where the standard approach as identified by Favero (2001, ch. 7) specifies a 12-month lead on inflation and current output. These leads are at odds with published statements by the Bank of England which emphasize that the full ‘impact of a change in interest rates on consumer price inflation takes up to about two years’, while the corresponding lag for output is up to about one year; these statements imply that the Bank ought to be setting interest rates in response to forecasts for inflation around eight quarters ahead (and output around four quarters ahead), and this is how it is generally believed to operate.

The second issue is the role of a lagged dependent variable in the reaction function, where the standard approach includes such a variable and interprets its presence as allowing for interest rate smoothing. However, there is considerable doubt as to whether the Bank of England really smoothes (see, for example, Cobham, 2003), and some former members of the Monetary Policy Committee have rejected the claim (see, for example, Goodhart, 2005).⁹

In order to investigate these issues further, I compare the results of two different techniques for estimating the Bank of England’s reaction function, for the period 1997 to 2007: the standard approach exemplified by Clarida, Galí and Gertler (1998, 2000) and what we shall call the ‘ex ante forecast’ approach used by Goodhart (2005).

Section 2.2 introduces the issues and the two estimation approaches. Section 2.3.1 presents the results of estimations of the standard approach over the period since the Bank was given control of interest rates (operational independence) in mid-1997, with varying leads on inflation and the output gap. Section 2.3.2 extends and confirms Goodhart’s (2005) findings, and shows the results of systematic variation of the leads on inflation and output growth. Section 2.4 compares the two sets of findings. Section 2.5

⁹ Similar doubts have been expressed with respect to smoothing by the Federal Reserve Board in the US, and Rudebusch (2002, 2006) has provided considerable indirect evidence against such smoothing.

applies the ex-ante approach to the case of the ECB. Section 2.6 concludes.

2.2. Two approaches

Taylor put forward his instrument rule for monetary policy in 1993 both as a recommendation of how policy should be operated and as a rough description of what the Federal Reserve Board had done in recent years. The original Taylor rule suggested the Fed rate should respond to contemporaneous inflation and output gap with the coefficients of 1.5 and 0.5 respectively. Taylor didn't specify the target of the central bank—whether it should target inflation only or the real output gap as well – but focuses instead on how the central bank should adjust its instrument. The implied reaction function contains information on both policy makers' preferences and the structure of the economy. To investigate policy makers' preferences, the standard analysis usually considers the minimization of the central bank's loss function together with other sectors' optimization problems. Woodford (2003) and Favero (2001) have discussed this in a New Keynesian model which consists of three equations:

$$\text{The demand equation: } y_{t+1} = \beta_y y_t - \beta_\gamma (r_t - E_t \pi_{t+1} - rr_e) + \mu_{t+1}^d \quad (2.1)$$

$$\text{The Phillips Curve: } \pi_{t+1} = \pi_t + \alpha_y y_t + \mu_{t+1}^s \quad (2.2)$$

$$\text{And the intertemporal optimization problem: } \text{Min } E_t \sum \delta^i L_{t+i} \quad (2.3)$$

$$\text{where } L = 0.5[(\pi_t - \pi^*)^2 + \lambda y_t^2]$$

By first-order differentiation of the equation (2.3) and combining the three equations, they derived an interest rate rule:

$$r_t = rr_e + \pi^* + \left(1 + \frac{1}{\alpha_y \beta_\gamma}\right) (E_t \pi_{t+1} - \pi^*) + \frac{\lambda}{\delta \alpha_y k} \frac{1}{\alpha_y \beta_\gamma} E_t y_{t+1} + \frac{\beta_y}{\beta_\gamma} y_t \quad (2.4)$$

Where $k = 1 + \frac{\delta \lambda k}{\lambda + k \delta \alpha_y^2}$, y represents deviations of output from its natural level, r_t is the policy rate, rr_e is the equilibrium value of the rate, λ represents policy makers' preference on output gap, π^* is the target inflation rate and δ is the discount factor. $(\beta_y, \beta_\gamma, \alpha_y, rr_e)$ describe the structure of the economy. For further details, see Favero (2001, p.241)

If we just estimate the single reaction function (2.4), it is impossible to identify either the parameter describing the central bank's preference or those describing the structure of the economy. However, we can still get some useful information. When $\lambda=0$, it indicates that the policy makers do not care about output (which might mean they were doing strict inflation targeting). So if the estimate of the coefficient of the expected output gap is zero, we can tell that the output gap is not in the central bank's loss function. However, if it is not zero, we still cannot reject the possibility that the central bank is targeting inflation only. Woodford suggested that output gap is useful in modeling inflation dynamics. (Woodford 2003, p 613) With nominal rigidity, the output gap has a close relationship with inflation in the future. And allowing the output gap in the loss function does not mean that policy makers have dual targets.

With respect to the policy makers' preferences, another question related to the Taylor rule has attracted more attention in recent years, and that is the value of the coefficient on inflation. The original Taylor rule gave signs for the coefficients and indicated the magnitude of response to inflation was larger than one, in which condition the change in interest rate was strong enough to stabilize inflation. Moreover, Taylor (1999) has shown clearly that if the coefficient on inflation is smaller than one, a positive inflation shock will lead to a rise in the nominal interest rate which would not be sufficient to prevent the real rate from declining, in which case inflation will rise further, and the system will be unstable. Equation (2.4) also indicates that when the optimization problems in all sectors are considered, a successful policy rule which stabilizes inflation well shows a larger than one coefficient when α_γ and β_γ are for theoretical reasons unlikely to be negative. On the other hand, when I estimate the reaction function of the BoE using the ex ante forecast approach, I am regressing the policy rate on the authorities' forecasts of inflation and output growth (which must encompass the structure of the economy as they perceive it). The regression coefficients therefore represent much more clearly than in the GMM approach the behaviour of the authorities in response to (their forecasts of) inflation and output growth

There has been a large amount of empirical work in recent years designed to identify how exactly different central banks in different periods have behaved. The tone for this work was set by the work of Clarida, Galí and Gertler (hereinafter CGG) (1998), which developed an errors-in-variables/Generalised Methods of Moments (GMM) approach to estimate monetary policy reaction functions and applied it to the US, Japan and

Germany (the 'G3' countries) and France, Italy and the UK (the 'E3'). In the first three an interest rate (typically the three month interbank rate) was regressed in a forward-looking manner on the output gap and on inflation, with a lagged dependent variable which was interpreted as allowing for interest rate smoothing.

CGG's 1998 paper was also one of those first attempts to estimate a reaction function for the UK. They included the German short term interest rate as an extra explanatory variable on the grounds that the UK was managing its currency against the Deutsche Mark (DM) over their period, which extended from the start of the Thatcher government in June 1979 to the UK's entry into the Exchange Rate Mechanism of the European Monetary System in October 1990.¹⁰ When this variable was not included the inflation coefficient was just under unity; but when it was included the inflation coefficient was only 0.48 but the coefficient on the German interest rate was 0.60. CGG interpreted this as suggesting that the Bank of England set interest rates as a weighted average of the German rate (with a weight of 0.6) and a domestic policy rule (weight 0.4) with an inflation coefficient of 1.20. CGG used leads of zero on output and 12 months on inflation; they justified the latter as follows: "*Based on our casual sense of how central banks operate, I choose a horizon of one year... Policy makers... are more concerned about medium and longer term trends [in inflation]... the year ahead forecast seems a good indicator of the medium term trend in inflation*" (1998: 1042).¹¹ The coefficient on their lagged dependent variable was 0.87.

Key features of some other investigations of the UK which use broadly the same approach are identified in Table 2.1. Angeloni and Dedola (1999) and Kuttner and Posen (1999) use the same leads as CGG: 12 months for inflation and zero for the output gap. Adam, Cobham and Girardin (AGG) (2005) used 9 and zero (which emerged from a wider search across a grid of periods). Nelson (2000) used leads of zero or one, for both quarterly and monthly data. Most estimates for the lagged dependent variable were around 0.85 for monthly data, but Nelson had lower values especially, as would be expected, when he used quarterly data.

¹⁰ There is no doubt that the pound-DM exchange rate was an important consideration in UK monetary policy from some point in the mid-1980s, and the UK 'shadowed' the DM between March 1987 and March 1988. But in the early years of the period policy was aggressively domestic in orientation, with very little attention paid to the exchange rate or the external context (see Cobham, 2002).

¹¹ They also stated that their results were not sensitive to changes of 6-9 months in the lead on inflation, or to the introduction of a 3-6 month lead on output.

A different approach, with different results, was used by Goodhart (2005). Instead of instrumenting within a GMM framework, Goodhart reconstructs what he calls *ex ante* forecasts of inflation and output growth: these are the forecasts that the MPC would have had in front of it *before* it made the interest rate changes, derived by applying information from the Bank of England's published statement on 'The Transmission Mechanism of Monetary Policy' (Bank of England, 1999) about the effects of interest rate changes on future inflation and output growth to the published quarterly forecasts.¹² He then uses these forecasts, in the form of their deviations from the inflation target and the underlying trend of output growth, respectively, in OLS regressions. He does this first with the level of the policy interest rate as the dependent variable and then, when the coefficient on the lagged dependent variable turns out to be insignificantly different from unity, with the change in the policy rate regressed on the (deviations of the) levels of the inflation and output growth forecasts. And in each case he considers leads on inflation and output growth varying (together) from zero to eight quarters.

The results are in striking contrast to those of the standard approach. Goodhart gets a much better fit for the regressions where the time horizon is seven or eight quarters (on both inflation and output growth), and in these cases the coefficients on inflation are significantly above unity (so that the Taylor Principle that real interest rates should rise in response to a rise in inflation is fulfilled) while the coefficients on output growth are typically not significant. In addition lagged terms on the change in the policy rate turn out to be insignificant, which Goodhart interprets as implying that the MPC does not engage in 'gradualism'.

In the next two sections I present comparable results for the standard and the *ex ante* forecast approaches, using quarterly data over the same time period (1997 Q3 to 2007 Q4).¹³ I confirm that the basic results of Goodhart's analysis (which only went up to 2003 Q3) hold for the longer period. And I estimate both approaches over a full 'grid' of leads on inflation and the output gap (for the standard approach) or output growth (for the *ex ante* forecast approach), varying each lag separately from zero to eight quarters

¹² Goodhart uses output growth (since four quarters earlier) because that is the variable for which the Bank publishes forecasts. As he points out, the Bank has not published explicit data for output gaps (see also Adam and Cobham, 2009: 105-7).

¹³ Since the Bank of England publishes forecasts on a quarterly basis only, we can only do this with quarterly data. It should be noted that while Clarida, Galí and Gertler used monthly data in their (1998) paper they used quarterly data in their longer study (2000) of the US.

(however, I restrict the lead on the output variable to be equal to or less than that on inflation, in line with conventional ideas on the transmission mechanism). I then compare these two sets of results in section 2.4. The application on the euro area is in section 2.5.

TABLE 2.1: Selected tests of the standard approach

	<i>Period</i>	<i>Inflation</i>	<i>Output</i>	<i>Lagged variable</i>	<i>dependent</i>	<i>Horizons (months)</i>	<i>Other variables and weight</i>
Clarida et al. (1998)	1979M6-1990M10	0.48	0.28	0.87		(12,0)	German interest rate 0.60
Angeloni and Dedola (1999)	1980M1-1987M12	0.72	0.60	0.87		(12,0)	German interest rate 1.32, as well as M3, real exch rate
	1988M1-1997M4	0.32	0.73	0.86		(12,0)	German interest rate 0.45, \$/DM exch rate
Kuttner and Posen (1999)	1984M1-1989M12	1.64	-0.21a	0.86		(12,0)	--
	1992M10-1999M4	0.52a	-0.29	0.79		(12,0)	--
Muscattelli et al. (2002)	1985Q1-1999Q1	1.40	0.57	not reported		(1,0)	--
Nelson (2000)	1979Q2-1987Q1	0.38	0.15	0.37		(0,0)	--
	1987M3-1990M9	0.00	0.45	0.52		(1,0)	German interest rate 1.11
	1992Q4-1997Q1	1.27	0.47	0.29		(1,0)	--
Adam, Cobham and Girardin (2005)	1997M4-2002M7	1.89	1.30	0.85		(9,0)	--

Note a not significant

2.3. Estimations for the two approaches

2.3.1. The standard approach

Here I follow closely the method pioneered by Clarida, Galí and Gertler (1998). The specification I estimate is

$$r_t = (1-\rho)\alpha + (1-\rho)\beta\pi_{t+j} + (1-\rho)\gamma y_{t+k} + \rho r_{t-1} + v_t \quad (2.5)$$

where the interest rate r reacts to inflation π and the output gap y , $(1-\rho)\alpha$ is the constant term, and a lagged dependent variable is included on the right hand side to allow for smoothing, in line with the standard approach. This equation can be thought of as being derived from a Taylor rule for the ‘desired’ policy rate and a partial adjustment of the actual rate towards the desired level, as follows:

$$r^*_t = \alpha + \beta\pi_{t+j} + \gamma y_{t+k} \quad (2.6)$$

$$r_t = (1-\rho)r^*_t + \rho r_{t-1} + \varepsilon_t \quad (2.7)$$

The error term in the estimating equation (2.5) consist of two parts: the forecast error and the exogenous shock,

$$v_t = - \{ (1-\rho)\beta(\pi_{t+j} - E_t \pi_{t+j}) + (1-\rho)\gamma(y_{t+k} - E_t y_{t+k}) \} + \varepsilon_t \quad (2.8)$$

and it is assumed that the forecast errors are uncorrelated with the current interest rate. The coefficients to be estimated, i.e. $(1-\rho)\alpha$, $(1-\rho)\beta$ and $(1-\rho)\gamma$, are the short run coefficients; long run equivalents can be obtained by dividing these by $(1-\rho)$ where ρ is the estimated coefficient on the lagged dependent variable

The Bank of England’s target was expressed in terms of the RPIX inflation index up to the end of 2003, and then in terms of the CPI (with the target itself being adjusted downwards from 2.5% to 2%, a change which was regarded as reflecting the difference in the index rather than a change of underlying objective). Since the Bank publishes the CPI for the years before 2004, I use those data here for the whole period.

The output gaps for the UK, the US and the eurozone are constructed by detrending

with the HP filter, with the smoothing parameter set to 1600.¹⁴ This technique was chosen as the most common method of detrending, but over this period, where the cyclical fluctuations are relatively small, the choice of technique is unlikely to make much difference (see Adam and Cobham, 2009).

The interest rate used is the official Bank rate. Other work in this vein has tended to use a 3-month interbank rate, but for an economy like the UK this rate may reflect international arbitrage pressures as well as official policy decisions. ACG found that the policy rate produced results very close to those for the interbank rate, though they were also a little less well-defined.

The basic idea of using GMM to estimate the reaction function comes from the orthogonal relationship between the instruments and the error term. As the error term v_t is correlated with the independent variables, I need some instruments which are highly correlated with inflation and the output gap but not with the forecast error and exogenous shock. I therefore include in the instrument set the variables used by Clarida et al., that is lagged interest rates, lagged inflation rates, lagged output gaps and the lagged world commodity price index, to which I added lagged output gaps for the US and the eurozone.

Table 2.2 presents the values of β and γ (the long run coefficients on inflation and the output gap) derived from the coefficient estimates in regressions of (2.5), with j , the lead on inflation, and k , the lead on the output gap, varying from zero to eight quarters, but with $k \leq j$. In each cell the upper number is the estimated value of β and the lower number is the estimated value of γ . Estimates in bold italics are significantly different from zero at the 1% significance level, those in bold (only) at the 5% level, those in italics (only) at the 10% level, and those in regular font are not significantly different from zero. Table 2.3 presents the root mean squared errors (RMSEs) for each of these regressions.

¹⁴ GDP data from 1980 were used for the calculation of the UK output gap, and data from 1995 for the US and the eurozone.

TABLE 2.2: Estimated values of β and γ by the standard approach with varying time horizons

β	$k=0$	1	2	3	4	5	6	7	8
γ									
j=0	1.85 4.17								
1	1.70 4.10	1.23 3.26							
2	1.69 3.57	1.27 3.23	1.42 2.09						
3	1.58 3.54	1.86 3.60	1.98 2.65	2.78 -0.32					
4	2.06 3.32	2.13 3.27	2.68 2.15	3.97 0.01	3.60 -0.86				
5	2.07 3.34	2.57 4.18	5.14 4.87	13.44 -1.60	8.93 -3.52	7.43 -0.40			
6	2.01 4.15	1.72 3.42	3.20 3.25	3.68 -0.09	3.29 -2.01	3.38 -0.49	2.85 0.64		
7	1.44 4.02	0.86 3.44	0.95 2.51	1.10 -0.77	1.33 -1.98	0.85 -0.27	0.80 0.04	0.81 -0.04	
8	1.27 3.82	0.41 3.06	0.58 2.26	0.59 -0.89	0.92 -2.03	0.41 -0.82	0.48 -0.26	0.42 -0.61	1.36 -3.77

Notes: colour coding as follows:

Bold and italic: significantly different from zero at 1% significance level

Bold: significantly different from zero at 5% level

Italic: significantly different from zero at 10% level

Regular: not significantly different from zero at 10% level

TABLE 2.3: Root mean squared errors for standard approach regressions with varying time horizons

RMSE	$k=0$	1	2	3	4	5	6	7	8
j=0	0.282								
1	0.287	0.283							
2	0.271	0.270	0.296						
3	0.273	0.267	0.294	0.311					
4	0.276	0.266	0.291	0.305	0.305				
5	0.272	0.269	0.288	0.304	0.304	0.302			
6	0.283	0.281	0.302	0.312	0.313	0.311	0.311		
7	0.295	0.293	0.314	0.323	0.323	0.322	0.322	0.323	
8	0.297	0.298	0.319	0.329	0.328	0.327	0.328	0.329	0.328

From Table 2.3 the RMSEs vary between 0.266 and 0.329, with higher values towards the south-east of the table, where the leads are both closer to 8, and the lowest values at $k = 1$ and $j = 3$ or 4. Towards the south-east of the table the coefficients of β and γ as shown in Table 2 are typically insignificant, and in the case of γ often negative. For $k \leq 2$ and $j \leq 6$, on the other hand, the coefficients are typically positive and significant, but although β is often > 1 , γ is often $> \beta$. It seems clear, therefore, that the standard approach provides results which are stronger and partly in line with prior expectations (which would usually have $\gamma < \beta$), but only for time horizons which are much shorter than those emphasized by the Bank of England and which are not consistent with the lags in the Bank's view of the transmission mechanism. For horizons consistent with the MPC's modus operandi, e.g. $j = 8$ and $k = 4$, the standard approach finds that the interest rate response to inflation is just under 1 and significant only at the 10% level, while the response to the output gap is significantly negative at the 5% level.

Table 2.4 shows the values of the coefficient on the lagged dependent variable for the same grid of regressions. These vary between 0.874 and 0.984. They tend to be higher and often not significantly different from unity towards the south-east of the table, but there is no clear pattern. For the 'best' fits with $k = 1$ and $j = 3$ or 4, however, the lagged dependent variable coefficients are significantly different from unity (and from zero) at 0.888 and 0.890.

TABLE 2.4: Estimates of ρ for the standard approach

ρ	k=0	1	2	3	4	5	6	7	8
j=0	<i>0.883</i>								
1	<i>0.893</i>	<i>0.874</i>							
2	<i>0.879</i>	<i>0.874</i>	<i>0.902</i>						
3	<i>0.880</i>	<i>0.888</i>	<i>0.912</i>	0.955					
4	<i>0.892</i>	<i>0.890</i>	<i>0.907</i>	0.947	0.948				
5	<i>0.898</i>	<i>0.918</i>	0.947	0.984	0.979	0.972			
6	<i>0.929</i>	<i>0.906</i>	0.947	0.966	0.967	0.963	0.952		
7	<i>0.923</i>	<i>0.893</i>	0.930	0.944	0.948	<i>0.928</i>	<i>0.927</i>	<i>0.925</i>	
8	<i>0.908</i>	<i>0.882</i>	<i>0.924</i>	0.944	<i>0.945</i>	<i>0.919</i>	<i>0.925</i>	<i>0.919</i>	<i>0.951</i>

Notes: colour coding as follows:

Bold and italic: significantly different from 1 at 1% significance level

Bold: significantly different from 1 at 5% level

Italic: significantly different from 1 at 10% level

Regular : not significantly different 1 zero at 10% level

I have also estimated, but do not report for space reasons, the same equation but without

a lagged dependent variable. In these regressions the inflation coefficient is nearly always negative, and often significantly less than zero, while the output gap coefficient is in most cases around 1 and significant. In addition the RMSEs are typically three to four times larger than those when the lagged dependent variable is included. It is clear, therefore, that to get ‘decent’ results it is essential to include the lagged dependent variable.

Finally, given the recent emphasis by Mavroeidis (2004) and Consolo and Favero (2009) on the issues of identification and weak instruments,¹⁵ the results of applying the Cragg-Donald (1993) test for weak instruments are reported in Table 2.5. This shows that in most cases, including the best fit cases $k = 1$ and $j = 3$ or 4 , the regressions fail the weak instruments test (and this is despite the fact that I have extended the instrument set from that of CGG by including output gaps for the US and the eurozone).¹⁶

TABLE 2.5: Cragg-Donald tests for weak instruments in standard approach

<i>C-D</i>	<i>k=0</i>	1	2	3	4	5	6	7	8
<i>j=0</i>	5.107								
1	4.494	4.477							
2	5.086	7.106	7.038						
3	4.724	5.655	5.939	5.229					
4	4.3	5.633	9.227	6.788	7.547				
5	3.969	4.981	7.506	7.241	6.086	3.655			
6	2.378	2.951	3.375	2.961	3.299	3.143	3.257		
7	2.212	1.888	2.212	1.983	2.162	1.954	2.067	2.215	
8	6.603	4.751	7.006	6.344	7.104	4.159	5.289	3.85	2.87

Stock-Yogo (2002) weak ID test critical values:

5% maximal IV relative bias	20.65;	10% maximal IV relative bias	11.05	
20% maximal IV relative bias	6.07;	30% maximal IV relative bias	4.33	
10% maximal IV size		51.70;	15% maximal IV size	27.56
20% maximal IV size		19.38;	25% maximal IV size	15.19

2.3.2. The ex ante forecast approach

Here I follow the method set out by Goodhart (2005), the first step in which is to

¹⁵ Mavroeidis (2004) emphasises that the weak instruments problem arises ‘naturally’ when the predictable variation in inflation is low relative to unpredictable future shocks. Consolo and Favero (2009) favour a reverse form of the regression with inflation as the dependent variable; in this case they find significantly less inertia in monetary policy.

¹⁶ The results of weak instrument tests when these output gaps are excluded are broadly similar to those reported here.

reconstruct the ex ante forecasts of inflation and output growth, that is the forecasts the MPC would have had in front of it before it made its interest rate decisions.¹⁷ First, I use data from Bank of England (1999) which gives the expected effect on inflation and output growth over successive quarters of changes in the policy rate, as in Table 2.6. I then assemble the forecasts for inflation and output growth over 0-8 quarters ahead as published with successive *Inflation Reports*; these are what Goodhart calls the ex post projections. I then take the interest rate changes in the month in which each *Inflation Report* was published, together with any changes in the preceding two months, multiply these numbers by the numbers in Table 2.6 and subtract the implied effects on inflation and output growth from the ex post projections in order to get the ex ante forecasts.¹⁸

Table 2.6: The effect of interest rate changes on inflation and output growth according to the Bank’s model of the transmission mechanism

a) Inflation

quarters ahead	0	1	2	3	4	5	6	7	8
policy rate changes									
0.25%				0.01	0.03	0.05	0.06	0.08	0.08
0.5%				0.02	0.06	0.1	0.12	0.15	0.15
0.75%				0.03	0.08	0.14	0.18	0.24	0.24
1%				0.04	0.11	0.18	0.25	0.32	0.32

b) Output growth

quarters ahead	0	1	2	3	4	5	6	7	8
policy rate changes									
0.25%	0.01	0.03	0.05	0.07	0.09	0.09	0.07	0.06	0.04
0.5%	0.02	0.06	0.10	0.14	0.18	0.18	0.14	0.12	0.08
0.75%	0.03	0.09	0.15	0.21	0.26	0.25	0.21	0.18	0.12
1%	0.03	0.12	0.21	0.30	0.35	0.35	0.29	0.25	0.16

Source: Bank of England (1999)

Figure 2.1 illustrates the results: it shows the resulting ex ante forecasts for inflation,

¹⁷ Following Goodhart, I consider together the changes in interest rate over the two months preceding the publication of each *Inflation Report*, with its forecasts, as well as the changes made in that month. Over the period as a whole just over half of all policy rate changes were made in *Inflation Report* months, when the MPC would have had in front of it a completely new forecast, as opposed to intervening months when no new full forecast would have been available

¹⁸ We use the RPIX forecasts up to 2004 Q1, when the MPC produced forecasts for both RPIX and CPI, and the CPI forecasts (with the lower target) thereafter.

together with the published ex post forecasts, for two particular horizons, four and eight quarters ahead. The four quarter ahead forecasts in Figure 2.1(a) fluctuate widely but are always close to each other, which reflects the fact that the changes in the policy rate which are included in the ex post but not the ex ante forecast have only small effects within this time horizon (and the incidence of no-change quarters). The eight quarter ahead forecasts in Figure 2.1(b) are less close to each other, the ex post forecast in particular fluctuates less widely (it remains nearly always within 0.2% of the target) and they both show a distinct fall in 2004 when the inflation target was changed from 2.5% on the RPIX to 2% on the CPI.

Once these forecasts are available, they can be used in simple OLS regressions to find how interest rate decisions are related to them. The first specification which Goodhart estimated was

$$r_t = a + b(E_t \pi_{t+j} - \pi^*) + c(E_t g_{t+k} - g^*) + dr_{t-1} + \varepsilon_t \quad (2.9)$$

where the policy interest rate r reacts to the difference between forecast and target inflation π and the difference between forecast and trend output growth g , a is the constant, and a lagged dependent variable is included on the right hand side.

Figure 2.1(a): Ex post and ex ante forecasts of inflation four quarters ahead

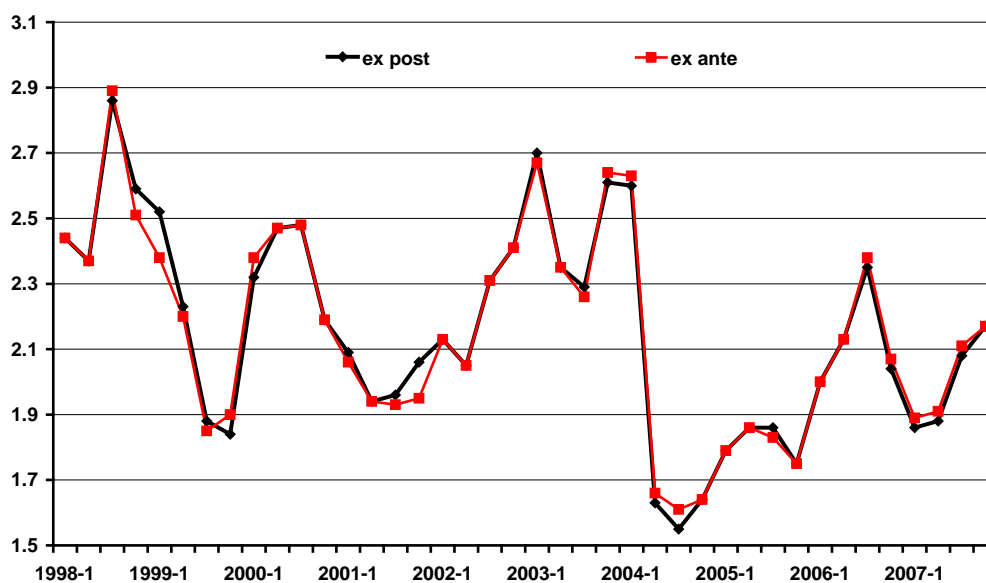
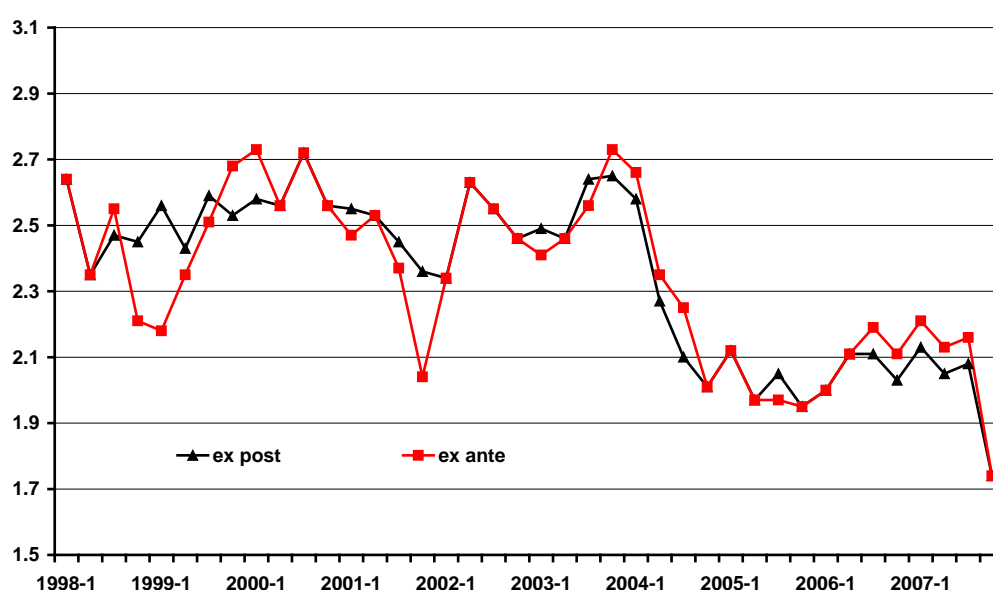


Figure 2.1(b): Ex post and ex ante forecast of inflation eight quarters ahead



Inflation is the four-quarter growth of the RPIX index up to the first quarter of 2004, with the target at 2.5%, and then the four quarter growth of the CPI, with the inflation target at 2%. Output growth here is the growth of GDP since four quarters before, with trend growth set at 2.25%. The main reason for using output growth rather than the gap is that the Bank's forecasts are for the former rather than the latter, but it seems more likely that the MPC reacts to the former rather than the latter, which it does not identify (Adam and Cobham, 2009). As Sauer and Sturm (2003) have shown, growth rate cycles tend to lead growth cycles, so that output growth can be seen as a forward indicator of the output gap: we should therefore expect a shorter lead on output growth than on the output gap.

When Goodhart estimated equation (2.9) he found that the coefficient on the lagged dependent variable was insignificantly different from unity. He interpreted this as implying that the equation was misspecified, and went on to estimate an equation for the change in interest rates. I examined this directly by testing for unit roots in Table 2.7. Although the period is longer than Goodhart's, it is still rather short for unit root tests to have much power. However, the evidence indicates that the interest rate is stationary only in first difference form, whereas the deviation of inflation from target and output growth from trend may be stationary in levels. In addition, Wald tests for the different horizons indicate that in nearly all cases, and certainly in the $k = 0$ or 1 , $j = 7$ or 8 , cases

d is insignificantly different from 1. I therefore tested the following specification, which is a rearrangement of (9) for the case where $d = 1$:

$$\Delta r_t = a + b(E_t \pi_{t+j} - \pi^*) + c(E_t g_{t+k} - g^*) + e \Delta r_{t-1} + \varepsilon_t \quad (2.10)$$

where Δr is the first difference of the interest rate and, following Goodhart, I included a lagged term in this difference to test for gradualism. The results showed that the lagged dependent variable was almost always insignificant, so I dropped it in favor of the following specification:

$$\Delta r_t = a + b(E_t \pi_{t+j} - \pi^*) + c(E_t g_{t+k} - g^*) + \varepsilon_t \quad (2.11)$$

which corresponds to Goodhart's Table 12 equation.¹⁹

Table 2.7: Unit root tests

Interest rate

	T-statistic	Prob*
ADF	-0.91	0.94(null: r has a unit root)
PP	-1.16	0.90(null : r has a unit root)
KPSS	LM-statistic: 0.20	Null : r is stationary Critical values: 1% level: 0.22; 5% level:0.15; 10% level:0.12

Inflation deviation:

	j=0	1	2	3	4	5	6	7	8
ADF	-3.32 (0.07)	-2.68 (0.25)	-2.33 (0.41)	-2.12 (0.52)	-2.58 (0.29)	-3.67 (0.04)	-4.36 (0.006)	-4.20 (0.009)	-3.42 (0.06)
PP	-1.98 (0.59)	-1.13 (0.91)	-1.3 (0.87)	-0.58 (0.97)	-1.65 (0.76)	-3.27 (0.08)	-4.23 (0.009)	-4.23 (0.009)	-3.42 (0.06)
KPSS	0.13 (10%)	0.15 (5%)	0.15 (5%)	0.16 (5%)	0.16 (5%)	0.13 (10%)	0.099 ac	0.06 (ac)	0.096 ac

GDP growth deviation

	k=0	1	2	3	4	5	6	7	8
ADF	-4.09 (0.01)	-4.29 (0.008)	-2.71 (0.24)	-0.94 (0.94)	-1.06 (0.92)	-2.54 (0.31)	-3.54 (0.048)	-3.82 (0.026)	-3.75 (0.03)
PP	-3.19 (0.10)	-2.37 (0.39)	-1.74 (0.71)	-1.08 (0.92)	-1.28 (0.88)	-0.73 (0.96)	-1.43 (0.84)	-2.70 (0.24)	-3.58 (0.04)
KPSS	0.04 ac	0.08 ac	0.14 ac	0.18 (5%)	0.18 (5%)	0.17 (5%)	0.15 (5%)	0.07 ac	0.16 (ac)

¹⁹ There is one difference: Goodhart appears to have excluded the constant term from his regressions, arguing that when he took the first difference of the dependent variable on the left hand side of equation (2.5) the constant would drop out. This would be correct if equation (2.6) was the result of differencing all the variables in (2.5), but if it is a matter of assuming that $d = 1$ and rearranging the constant should still be there. In fact, the constant term in our equation (2.7) regressions is typically insignificant.

Goodhart reported regressions of this equation for the nine cases from $j = k = 0$ to $j = k = 8$, but I do this for the full grid, with j and k varying from zero to eight quarters but $k \leq j$, in Table 2.8. Table 2.9 reports the corresponding RMSE and LM statistics.

From Table 2.9 the RMSEs vary between 0.206 and 0.308, but they are systematically lower in the bottom two rows ($j = 7$ or 8) and the best fit, as indicated by the smallest RMSEs, is obtained when $j = 7$ or 8 and $k = 1$ or 2 . The LM statistics reported indicate that none of the residuals suffer from serial correlation. In Table 2.8 the values on the diagonal, where the leads on inflation and output growth are always the same, are broadly in line with what Goodhart found: as the horizon of the inflation and output growth deviations increases, the value of b increases while c is not significant at horizons of 7 and 8. When I allow for differences in horizon between inflation and output growth, i.e. I consider the grid as a whole, it is clear that for $j \leq 6$ the inflation coefficients are < 1 and nearly always insignificant while the output growth coefficients are positive and significant; but as j rises the estimated value of b rises, particularly after $j = 5$, and for $j > 6$ the inflation coefficients are significant and > 1 , while the output growth coefficients become smaller and ultimately insignificant. In other words, the response of the interest rate to inflation is strongest for $j = 7$ or 8 , while its response to output growth does not seem to vary systematically with k but is strongest for $j = 3$ to $j = 5$. In the group of cases where the RMSEs were lowest, that is $j = 7$ or 8 and $k = 1$ or 2 , the inflation coefficients are > 1 and the output growth coefficients small but positive and significant; for the very lowest RMSE, where $j = 8$ and $k = 1$, the inflation coefficient is 1.16 and the output growth coefficient is 0.17 and significant. In this case b is also significantly greater than 1. On the other hand, in the cases where the standard approach finds the strongest relationships, i.e. $j = 3$ or 4 and $k = 1$, the output growth coefficients are significant but the inflation coefficients are insignificant.

The results of the ex- ante forecast approach estimations, which are shown in table 2.8, are based on the Newey-West standard errors. I have also done bootstrap exercises on the regression. The coefficients are the same as those presented here and the RMSEs are also unchanged, which means this robustness check has no influence on the selection of horizons. I also ran estimations using the data to the end of 2008 when the interest rate was still decided in the same way as before and QE had not yet started. The results are

quite close to those in table 2.8 and table 2.9 and support the indication that policy makers respond to the forecast inflation deviation two years ahead²⁰ and output growth one quarter ahead. The coefficient of the inflation deviation two-years ahead is a bit smaller than that in table 2.8 but it still insignificantly different from 1. The coefficient of inflation at $j=4$ and $k=1$, which is suggested by the GMM method, is 0.2 and is insignificantly different from zero at the 90% level. When the horizon of output growth is larger than 3, the coefficient of the inflation deviation becomes significantly different from 0 though it is much lower than 1.

The financial crisis strongly affected the economy by a tightening in the credit market. The magnitude and the nature of these effects on the economy were different from anything experienced during the previous ten years. In particular, uncertainty around the inflation outlook became bigger. The weak identification problem for GMM would become severe if I included this period into the estimation and the results would have become more unreliable. Moreover, because the GMM method uses actual data for future inflation and output gap (on the assumption that there are no systematic errors in the forecasts), but from 2009 the level of output, in particular, was consistently much lower than what would have been expected, I prefer to stop the data in the end of 2007 which excludes the crisis period, although there is no substantial difference in the results.

²⁰ This time the smallest RMSE value appears at $j=7$ and $k=1$ but the RMSE at $j=8$ and $k=1$ is the second lowest value and is very close to it.

TABLE 2.8: Estimates of a, b and c by the ex ante forecast approach

<i>a</i>	<i>k=0</i>	1	2	3	4	5	6	7	8
<i>b</i>									
<i>c</i>									
j=0	-0.08 0.07 0.30								
1	-0.08 0.03 0.30	-0.10 -0.02 0.37							
2	-0.10 -0.07 0.29	-0.09 -0.01 0.37	-0.11 0.03 0.36						
3	-0.11 -0.09 0.29	-0.10 -0.02 0.37	-0.10 0.06 0.36	-0.11 0.11 0.33					
4	-0.07 0.10 0.29	-0.07 0.10 0.36	-0.07 0.24 0.35	-0.07 0.34 0.33	-0.08 <i>0.36</i> 0.36				
5	-0.04 0.24 0.27	-0.06 0.20 0.35	-0.05 0.34 0.33	-0.05 <i>0.43</i> 0.31	-0.06 <i>0.47</i> 0.34	-0.10 0.52 0.42			
6	-0.01 0.53 0.22	-0.04 0.38 0.32	-0.04 0.49 0.31	-0.04 <i>0.59</i> 0.28	-0.05 0.65 0.30	-0.07 0.71 0.37	-0.07 0.82 0.35		
7	0.01 1.36 0.07	-0.02 1.03 0.19	-0.03 1.04 0.18	-0.02 1.16 0.15	-0.03 1.23 0.17	-0.05 1.27 0.21	-0.05 1.39 0.21	-0.05 1.48 <i>0.20</i>	
8	-0.09 1.43 <i>0.11</i>	-0.09 1.16 0.17	-0.10 1.20 0.15	-0.10 1.34 <i>0.11</i>	-0.09 1.37 <i>0.09</i>	-0.11 1.45 <i>0.12</i>	-0.11 1.57 0.08	-0.11 1.62 0.07	-0.11 1.65 0.06

Notes: significance determined by robust standard errors, coded as follows:

Bold and italic: significantly different from zero at 1% significance level

Bold: significantly different from zero at 5% level

Italic: significantly different from zero at 10% level

Regular: not significantly different from zero at 10% level

TABLE 2.9: RMSE and LM statistics for the ex ante forecast approach

RMSE	k=0	1	2	3	4	5	6	7	8
LM (Prob.Chi - square)									
j=0	0.302 0.53								
1	0.303 0.560	0.254 0.969							
2	0.308 0.322	0.254 0.964	0.256 0.745						
3	0.307 0.388	0.254 0.976	0.255 0.783	0.274 0.186					
4	0.303 0.502	0.253 0.994	0.248 0.746	0.261 0.168	0.273 0.124				
5	0.299 0.361	0.250 0.855	0.243 0.599	0.255 0.138	0.266 0.106	0.271 0.137			
6	0.288 0.206	0.244 0.648	0.237 0.521	0.249 0.145	0.258 0.121	0.261 0.144	0.283 0.101		
7	0.231 0.206	0.212 0.358	0.211 0.490	0.215 0.294	0.217 0.313	0.214 0.349	0.219 0.322	0.223 0.258	
8	0.217 0.550	0.206 0.585	0.213 0.583	0.219 0.733	0.218 0.569	0.221 0.640	0.223 0.629	0.224 0.649	0.225 0.665

2.4. Comparisons and comments

Section 2.3.1 established three points on the standard GMM approach. First, this approach produces the best fits for horizons of three or four quarters on inflation and one quarter on the output gap, horizons which are broadly in line with those commonly used in this literature but are not in line with the horizons implied by the Bank of England's understanding of the transmission mechanism or, more generally, by its typical emphasis on the inflation forecast two years out. Second, this approach treats the relatively high values for the coefficient on the lagged dependent variable which it obtains as implying a high degree of interest rate smoothing; such smoothing is also inconsistent with statements made by those involved in or close to the decision-making process at the Bank. Third, the results at nearly all horizons suffer from the weak instruments problem, which means that the distributions of the estimators and the test statistics may be distorted, and that conventional inference may be invalid.

Section 2.3.2 established two corresponding points for the ex ante forecast approach. First, this approach produces the best fits for horizons of seven or eight quarters for inflation and one quarter for output growth: this inflation horizon is clearly consistent with the Bank's own view of its activities, while the output growth horizon (when output growth is seen as a forward indicator of the output gap, which in turn affects inflation with a lag of around four quarters) seems broadly plausible. Second, when the equation is estimated in terms of the first difference of the interest rate as the dependent variable, lags of the change in interest rates are not significant, which suggests that there is no 'gradualism' in UK monetary policy. Moreover, although the econometrics (as opposed to the data used) are much simpler in this case, the approach does not seem to suffer from any obvious econometric shortcoming.

Before I proceed to explain the different best fits suggested by two methods, I should make it clear that the best fits for the horizons do not suggest that policy makers don't look at other forward projections. Actually the MPC published ex post forecasts for inflation and output growth from 0 quarter ahead to 8 quarters ahead. And in the transmission mechanism report released by the BoE, it clarified that policy makers realized it takes time for an official rate change to have its full impact. For some transmission channels the influence is quick (like wholesale money-market interest rates) and for some it takes longer term (like mortgage interest rates). The empirical evidence

suggested that it takes one year for a monetary policy change to reach its peak effect on production and another year for the peak effect on inflation. Thus it is expected that the 'best fits' horizons chosen by the regressions, which suggests strongest and clearest reaction, should be where the interest rate decision impacts the economy fully. And this impact would develop gradually from the time of the interest rate decision. We cannot effectively regress the policy rate on the forecasts for each variable at each horizon in the same regression, However, we can do a systematic analysis of the reaction of the policy rate to each pair of horizons, and this will show which pair are seen as most important by the policymakers. I would expect the finding to be related to the BoE's published views on the transmission mechanism and its general emphasis on the forecasts two years ahead.

The most likely explanation of the differences between the two reaction functions is that the ex ante forecast approach employs something close to the actual forecasts produced by the central bank,²¹ using the wide array of different information at its disposal together with the judgments of its forecasters, whereas the standard approach uses a limited set of instruments to generate implicit forecasts in a more mechanical way so that its implicit forecasts are much less close to what the policymakers were considering. While it is not possible to back out the exact forecasts implied by the GMM approach, I can run OLS regressions for inflation as a function of all the instruments included in our GMM model, and use the result to predict the forecasts for inflation at different horizons (this is equivalent to carrying out the first stage of an IV procedure). Figure 2.2 graphs the four quarter ahead and eight quarter ahead 'instrument forecasts' for inflation generated in this way, together with the ex ante forecasts.²² It is immediately apparent that the instrument forecasts are not close to the ex ante forecasts, particularly in the later part of the period; the correlation between the instrument and ex ante forecasts is 0.33 for four quarters ahead and 0.23 for eight quarters ahead. The implication is that the GMM model is trying to relate the policy rate to something which is quite distant

²¹ A possible alternative explanation for the superior performance of the ex ante forecast approach might be that it uses additional information, in the form of the MPC's knowledge of its own likely changes in policy over the horizon period. But the ex post forecasts we use are those made on the assumption of constant interest rates, so in this sense they are comparable to those implied in the standard approach.

²² For purposes of comparison we have reduced the ex ante forecasts for inflation up to February 2004 by 0.5% in order to 'convert' them from RPIX forecasts (on a target of 2.5%) to CPI forecasts (on a target of 2%), since the GMM model uses the CPI throughout. It should be noted that we cannot carry out the same exercise for output, because the standard approach uses the output gap and the ex ante forecasts are for output growth.

from the forecasts which the policymakers were considering, and that would explain why it performs poorly.

With respect to interest rate smoothing the conventional intuition for this is that the policymaker decides that the interest rate needs to be changed by a certain amount, but chooses to spread that change over a number of periods. This intuition suggests precisely that the change in the interest rate should be related to the previous period change (rather than that the level of the interest rate should be related to its previous level, which is the form used in the standard approach and identified there as interest rate smoothing). In that sense the intuition is better tested by the inclusion of the lagged change in the interest rate in a reaction function which has the change in the rate as the dependent variable, than by including the lagged level of the rate in a regression with the rate on the left hand side. But when smoothing is tested in this way in the ex ante forecast approach, it is rejected.

Figure 2.2(a): Instrument and ex ante forecasts of inflation four quarters ahead

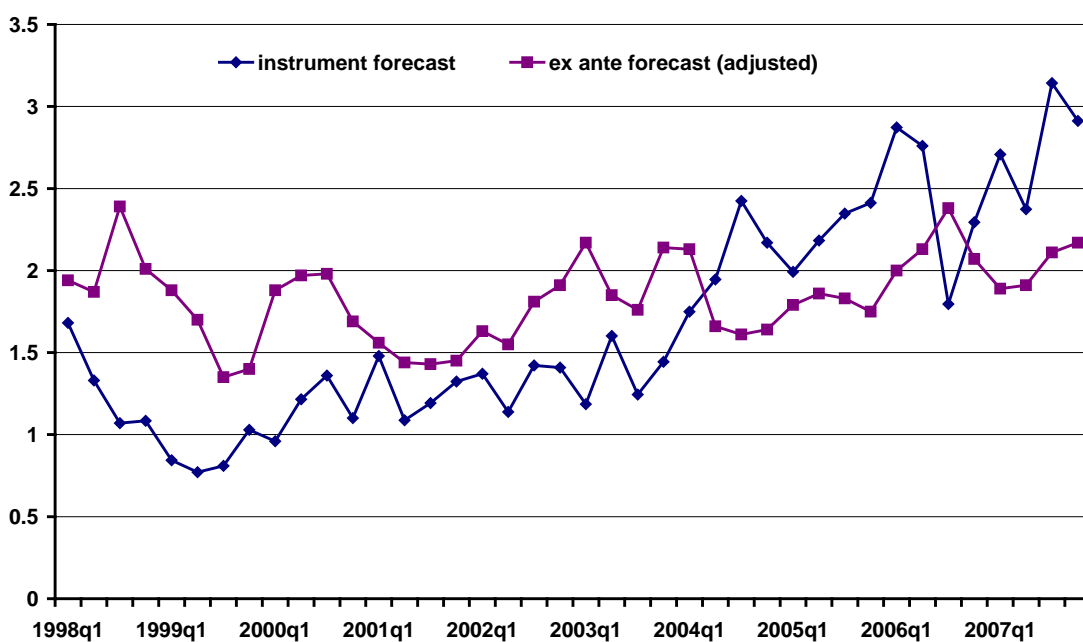
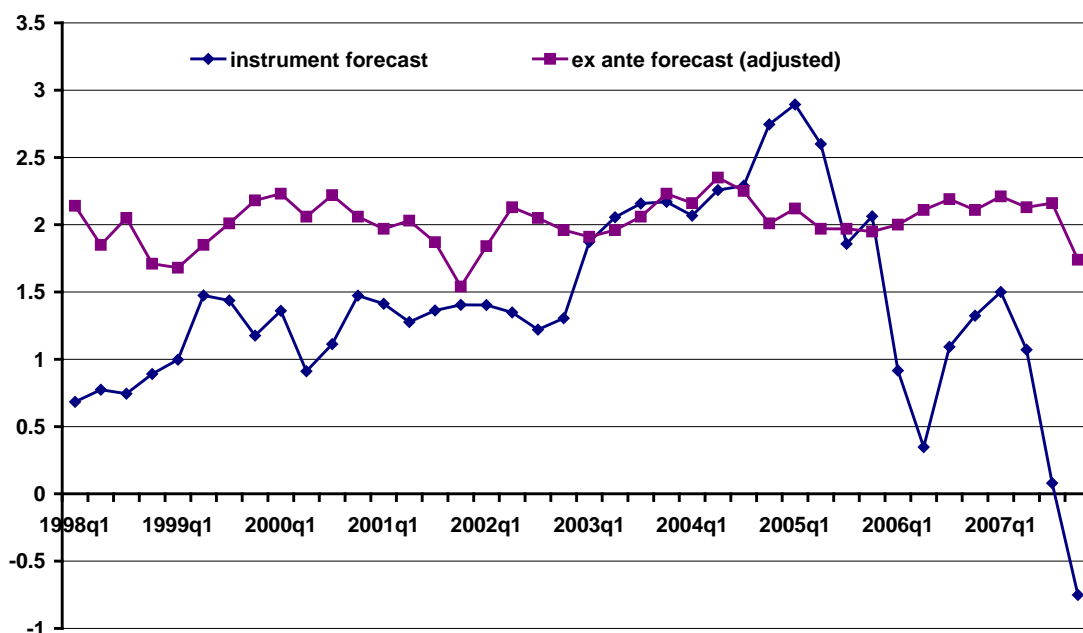


Figure 2.2(b): Instrument and ex ante forecasts of inflation eight quarters ahead



The implications of the two different approaches for the issue of smoothing can be elucidated by considering the adjustment of the interest rate over time to an inflation shock which, once it occurs, is recognised and expected with certainty to continue. Figure 2.3 graphs the cumulative rise in the interest rate in response to a (continuing) 1% rise in expected inflation, everything else remaining equal, for the best fit on the standard approach ($k = 1, j = 4$). It takes between five and six quarters for the nominal interest rate to rise by 1%, i.e. for the real interest rate to exceed its initial pre-shock level.²³ This is disturbing: the outcome for inflation over the period considered here suggests that policy was in fact being operated in a stabilising manner (and/or that the Taylor Principle was fulfilled), but such slow adjustment of the interest rate appears to mean that inflation shocks had time and scope to destabilise the economy before policy reasserted itself. In the ex ante forecast approach (for the best fit case of $j = 1$ and $k = 8$), on the other hand, the interest rate rises in the first quarter by 1.16% so that the real interest rate exceeds its initial level by the end of the first quarter.

²³ Within the current framework we cannot calculate the response of the economy (or inflation) to the interest rate change. But insofar as the rise in the interest rate leads to reductions in expected inflation and the output gap, the rise in the interest rate will be slower and/or smaller.

Figure 2.3: The policy rate response to a rise in inflation

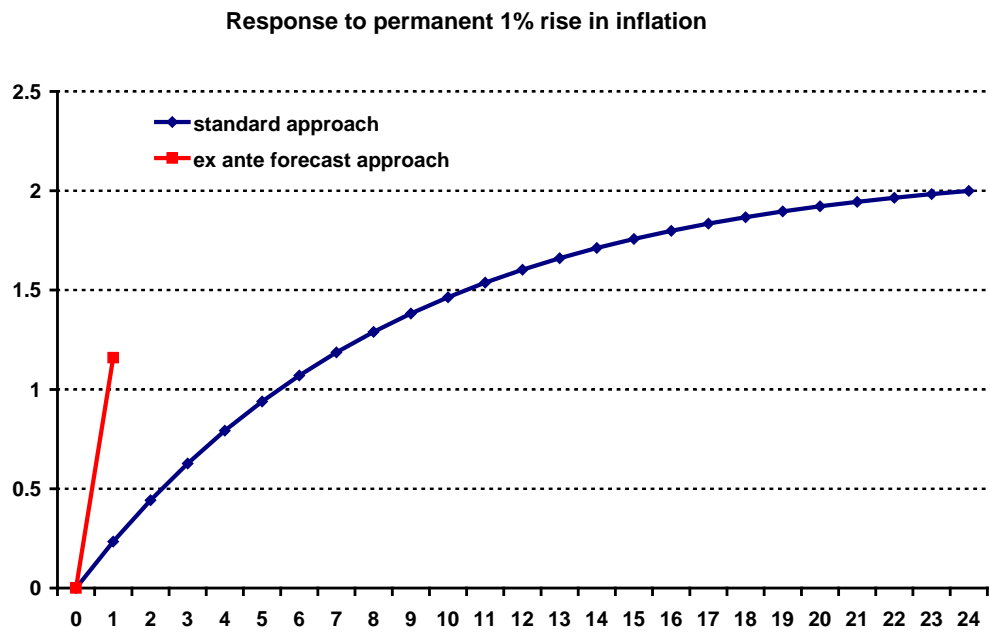
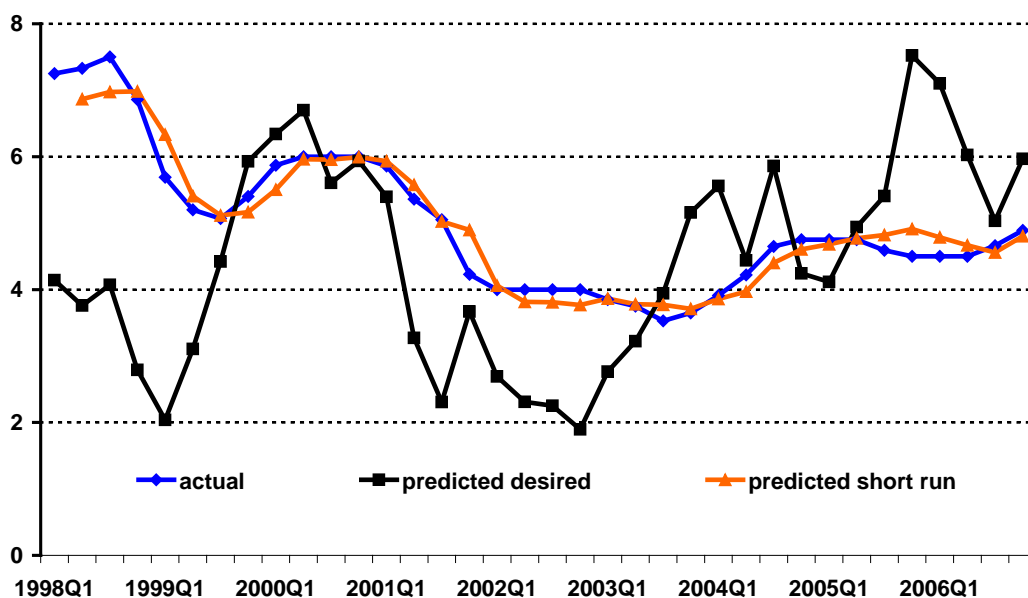


Figure 2.4 sheds some further light on the standard approach. It shows the actual policy rate together with the predicted desired rate r^* , which can be backed out from the regression using equation (2.6), and the predicted short run rate, that is the predicted value of the dependent variable in the regression of equation (2.5). It is immediately apparent that the desired rate has a very poor fit with the actual rate, and that the much better fit of the short run rate relies heavily on the lagged dependent variable (which, given the magnitude of its coefficient, accounts for some 89% of the short run rate). In particular there are large fluctuations in the desired rate in 1999, 2001-2, 2003-4 and 2005-6 which leave almost no trace on the much more stable short run rate.

Figure 2.4: Actual, predicted desired (r^*) and predicted short run policy rates



2.5. Estimates for the ex ante approach on the ECB

The ECB released an article on its monetary policy transmission mechanism in the ECB *Monthly Bulletin* in 2000, one and a half years after the ECB took responsibility of conducting monetary policy for the euro area. Compared with the monetary policy operations and transmission mechanism of the BoE, there are several points in common.

First, the ECB adjusts the official interest rate, which is referred to as the main refinancing rate, with a view to keeping prices stable. Although there is a reference value for broad money in the ECB, while it was ignored by the BoE, there was debate, in the period before unconventional monetary policy, as to whether money plays an active role or passive role in the policy of the ECB. (See *ECB Monthly Bulletin*, July 2000:46) As for the ambiguous role of money, the policy makers in the ECB neither dismissed it nor emphasized it in the transmission process.²⁴ On the other hand, the policy rate is the instrument policy makers use to influence the economy, as at the BoE. In their analysis of the transmission mechanism, the effect on macroeconomic activity starts from the change in the policy rate and then leads to changes in financial markets. Thus studying the change in policy rate, as I have done for the UK, is an important aspect in research on the monetary policy of the ECB. Secondly, it is emphasized in the article that there are lags before the policy changes pass through to macroeconomic activity and the setting of the monetary policy needs to be forward-looking. For the euro area, the change in the policy interest rate will first influence financial market conditions through several intertwined channels and then lead to changes in spending and the price level. Based on the transmission mechanism and some existing work on the effects of policy changes, a simple VAR model indicated a temporary fall in output after two quarters as a response to a 25 basis point rise in the interest rate. And the inflation rate started to fall after 6 quarters. (*ECB Monthly Bulletin*, July 2000:56) For the Bank of England these two time lags have been put at one year and two years, respectively.

As the ECB's monetary policy framework is similar to that of the BoE in some aspects, it is possible to estimate a policy reaction function, in which the interest rate responds to the deviation of inflation forecast and output gap forecast from their targets directly, rather than using GMM method. The biggest difficulty in doing so is how to calculate the 'ex-ante projections' for the ECB. In contrast to the Bank of England, the ECB does

²⁴ Gerlach and Svensson (2000) found that the money gap indicates future inflation but they also argued that this does not justify the prominent role of money in the strategy. See *Monetary Policy in the Euro Area: strategy and decision-making at the European Central Bank* : p.89.

not publish explicit projections of inflation and GDP growth for each quarter in the next two years. Their staff projections are only available for calendar years and are hard to use in estimating horizons. However, the ECB has conducted a Survey of Professional Forecasters (SPF) every quarter since 1999 to capture private sector expectations of macroeconomic variables. These expectations in the survey could be used as proxies in estimating the reaction function of the ECB. Frank Smets, who is Director General of the Directorate General Research of the ECB, has used the SPF projections instead of staff projections to estimate the ECB's policy reaction function. In his work, he used a simple rule proposed by Orphanides (2003) to illustrate how the ECB reacts to economic activity. The right-hand-side variables in the regression are the deviations of the SPF inflation forecast and deviations of the SPF output growth forecast. What's more, he calculated the desired policy rate by using the estimated parameters and found it captured the actual ECB's policy rate well. He suggests that "*the correlation between the SPF forecasts and the corresponding ECB projections is very high so that similar findings are obtained*". (See Smets 2010: 274) Under this 'official' suggestion, it is plausible to use SPF projections in the ex-ante forecast approach.

However, the SPF is not a perfect replacement for policy makers' projections. There are several issues in using it before I start the estimation. First, the SPF is conducted in the second half of the first month of each quarter, and it is independent of the interest rate setting process of the next month, most of which occurs at the beginning of that month. So those SPF projections are ex-ante projections rather than ex-post projections with respect to the decisions of the next month at least. Thus there is no need to extract the influence of the interest rate change from the SPF projections in the way in which this has been done for the ex-post projections in the UK. Second, it is not possible to be sure about the assumptions the participants were making when they answered the survey. In the UK case, the forecasts are made by the policy makers on a constant interest rate assumption. For the Euro Area, the Governing Council of the ECB generally decides the main refinancing rate in the first meeting of every month. When the participants in the

survey make their projections at the end of the first month,²⁵ they can either assume the policy rate is held constant, or they can forecast changes in the policy rate over the next two years and take these changes into consideration in making their inflation projections. Several of the surveys during 1999 and 2007 were even conducted at the same time as the interest rate decision meeting. There is no way to know how the participants took any changes made at that time into consideration.

Though there are drawbacks in using SPF projections, it is still worth trying to estimate the reaction function of the ECB with them. As in the UK case, I use the interest rate decision in the month when the SPF is published (the month after the SPF is conducted) as the policy rate level in that quarter, which responds to the deviation of the inflation forecast from target and to output growth. The results are shown in Table 2.10.

The SPF only supplies projections at one-year and two-year horizons. Therefore the estimation can only be undertaken for the time horizons where $j=4, 8$ and $k=4, 8$. As there are no projections for current inflation and GDP growth ($j=0$ and $k=0$), I use actual data to estimate how the policy rates respond to the variables at these horizons.²⁶ What's more, due to the fact that current GDP data is not available when the interest rate is made, the GDP growth in the previous quarter is the latest GDP data policy makers have. Estimations on lagged GDP growth reflect the attitudes of the policy makers to current available information. The inflation in the euro area is measured by the Harmonised Index of Consumer Prices (HICP) and the GDP growth rate is calculated from the annual difference of the log of the chained volume of GDP. The interest rate is the main refinancing rate. The target rates are taken to be 2% and 2.25% in HICP and GDP growth respectively.²⁷

²⁵ Since 2002, the survey has been conducted regularly at the end of Jan, Apr, Jul and Oct. Before that, it was conducted mostly at the beginning of Feb, May, Aug and Nov.

²⁶ Real Time Database of the ECB supplies the historical vintages of the data. The preliminary estimate of inflation generally comes out two months after while that of GDP comes out one or two quarters after. The revisions were made successively but very small.

²⁷ These targets are indicated in *Monthly Bulletin* and some working papers. If they were not right, they are still constant through the period. Which means the 'error' from the targets would affect only the estimate of the constant in the regression.

Table 2.10(a) shows the estimate of equation (2.11) for the ECB. The coefficient of inflation b increases from the north-west to the south-east of the table. In every column, as the horizon of inflation increases from 0 to 8, b increases. When $k=0$, the largest value of b is 0.96 at $j=8$. When the horizon of GDP growth increases too, the estimate of b can be 1.57 at the maximum. The coefficient of GDP growth c , on the other hand, does not always increase when the horizons change. It is clear that when k varies from -1 to 4, c increases on each of $j=0$, $j=4$ and $j=8$. And these estimates are all significantly different from zero at the 1% level. However, when k becomes 8, the estimate of c falls back to a lower level and it is not significantly different from zero at the 10% significance level.

Table 2.10 (a): Estimates of a , b and c by the ex ante forecast approach for the ECB

a	$k=-1$	$k=0$	4	8
b				
c				
$j=0$	0.03 -0.004 0.18	0.02 0.09 0.22		
4	0.09 0.25 0.16	0.09 0.26 0.20	0.20 0.56 0.35	
8	0.20 0.94 0.17	0.21 0.96 0.21	0.32 1.33 0.37	0.29 1.57 0.20

Notes: significance determined by robust standard errors, coded as follows:

Bold and italic: significantly different from zero at 1% significance level

Bold: significantly different from zero at 5% level

Italic: significantly different from zero at 10% level

Regular: not significantly different from zero at 10% level

Table 2.10 (b): RMSE and LM statistics

RMSE LM(4) (Prob.Chi -square)	K=-1	k=0	4	8
j=0	0.274 0.11	0.235 0.21		
4	0.270 0.10	0.234 0.22	0.257 0.43	
8	0.263 0.14	0.225 0.36	0.253 0.36	0.321 0.01

Table 2.10(b) reports the corresponding RMSE and LM statistics. The RMSEs are in the range of 0.22 to 0.27 except the one at $j=8, k=8$, which is above 0.30. When k 's value is fixed, the RMSE decreases as j increases in every column. When comparing the RMSE in different columns, it suggests that the RMSE drops from $k=-1$ to $k=0$ but then goes up when $k=4$. The smallest RMSE, indicated by the table, is the one when $j=8$ and $k=0$. The LM statistics also report no serial correlation except where $j=8$ and $k=8$.

Though it is hard to choose a 'best-fit' estimate due to the small number of forecast horizons given by the SPF, it is still possible to limit the range of it from the results in Table 2.10. As the RMSE decreases as k changes from -1 to 0 and increases as k increases from 0 to 8, the $k=0$ group of RMSEs indicates a better fit of the equation than the groups for other values of k . And in this column, the RMSE reaches its lowest level at $j=8$. So the most-possible horizons should be around $j=8$ and $k=0$. What is more, as the RMSE appears to have a "U-shape" from 0.263 to 0.225 then to 0.253 when k goes from -1 to 4, it is hard to judge where the lowest value of the RMSE lies. It is possible that from $k=0$ to 4, the RMSE decreases first in $k=1,2,3$ which we can not assess in this table and then increases again to a higher level. Thus I cannot reject the possibility that the 'best-fit' appears at $j=8$ and $k=1,2,3$. As the value of b increases from 0.94 to 1.57 as k becomes larger, the interest rate adjustment is strong enough to offset the inflation

pressure in the economy. What has to be emphasized here is that even $k=0$ does not mean the policy makers don't look forward on GDP growth. As what is well known, the data of GDP growth is hardly collected until the following quarter and the real-time data will only be available at least by that time. When SPF is conducted in the first month of the quarter, the information given to the participants is for GDP growth two quarters before. Thus I believe that when policy makers make interest rate decisions, the GDP data they have should be earlier than the GDP growth at $k=0$ in the estimation. Thus the GDP growth at $k=0$, which is actually calculated at a later time after the current quarter, should be taken as a forward-looking GDP one or two quarters ahead rather than the current figure.

Given the difficulty in knowing exactly what survey participants know and assume at the time of the survey, in addition to the results reported in Table 2.10, I also considered a different timing. The interest rate level I used in the regression this time, which responds to the SPF in that quarter, is the interest of the month which the forecast survey is made. In another word, the interest rate in the new estimation is one month earlier than the interest rate used previously. Table 2.11 show the results of the estimation. Generally speaking, the values of b and c in this table are quite close to results in Table 2.10. In Table 2.11(a), the values of b increase slightly than that in Table 2.10(a) at every horizon. When j increases from 0 to 8, the values of b increase gradually until they are around 1 and are significantly different from 0 at 5% significance level when $k=-1,0$ and at 1% level when $k=4,8$. The values of c are very similar to the previous estimations, which vary from 0.16 to 0.41. And the RMSE values in Table 2.11(b), however, indicate a better fit at $j=4$ and $k=4$, compare to the $j=8$ and $k=0$ in Table 2.10(b).

Though I have tried regressions with different timing, the latter results are less relevant to my question than the earlier set. In the earlier case the forecasts are clearly before, that is ex ante to, the policy decisions being considered, but in the latter case the forecasts may be partly ex post. For the ECB, there is some evidence that the short-term interest rate typically moves in advance of the main refinancing rate. (ECB *Monthly*

Bulletin, July 2000: 48, Chart 2) That might suggest that when the private sector makes its forecasts in the first month of the quarter, it is very likely to consider the possibility of an interest rate change in the second month, which is when the staff projections are made and the SPF projections are published. Thus though the interest rate used in the second set of estimation is the interest rate from the time when the SPF projections are actually made, the timing in the first set of estimations is much closer to what is meant by the ex ante forecast. So the first set of estimations is the preferred one.

From the estimates above, I suppose that the interest rate change in the Euro Area responds to the inflation projection 8 quarters ahead and GDP growth one or two quarters ahead. This suggestion is close to what the VAR model estimate indicates in a book published by the ECB in 2003 which summarised the research on the monetary policy transmission mechanism in the euro area (See Peersman and Smets, 2003). And it is also close to the pattern of the policy making process pronounced by the ECB in 2000.

Table 2.11 (a): Estimates of a,b,c by using rate at different timing

	$k=-1$	$k=0$	4	8
<i>a</i>				
<i>b</i>				
<i>c</i>				
j=0	0.03 -0.02 0.18	0.02 0.10 0.22		
4	0.12 0.41 0.16	0.13 0.43 0.19	0.23 0.70 0.39	
8	0.20 0.93 0.17	0.21 0.96 0.20	0.32 1.34 0.41	0.30 1.63 0.23

Notes: significance determined by robust standard errors, coded as follows:

Bold and italic: significantly different from zero at 1% significance level

Bold: significantly different from zero at 5% level

Italic: significantly different from zero at 10% level

Regular: not significantly different from zero at 10% level

Table 2.11 (b): RMSEs and LM statistics

RMSE LM(4) (Prob.Chi -square)	K=-1	k=0	4	8
j=0	0.263 0.34	0.229 0.27		
4	0.254 0.27	0.221 0.29	0.215 0.37	
8	0.252 0.40	0.220 0.41	0.224 0.27	0.312 0.02

2.6. Conclusions

In this chapter I have contrasted the standard GMM approach to estimating the monetary policy reaction function pioneered by Clarida, Galí and Gertler (1998) to the ex ante forecast approach developed by Goodhart (2005), which requires only simple OLS estimation, for the case of the Bank of England. It turns out that the latter produces a picture of monetary policy which is much closer to the Bank's own description of what it does, both in terms of the time horizons which give the best fit and in terms of the absence of gradualism, while the former suffers from econometric weaknesses in the form of weak instruments. The most likely explanation of these differences is that the ex ante forecast approach employs the actual forecasts produced by the central bank, using the wide array of different information at its disposal together with the judgments of its forecasters, whereas the standard approach uses a more limited set of instruments to generate implicit forecasts in a more mechanical way.

The implication is that economists who want to understand the policy process should try to apply the ex ante forecast method where possible. At present, few central banks publish forecasts that can be used in this way. This is unfortunate, for the standard approach is a very poor alternative. However, central banks must have the information required: in the name of transparency and in order for their decision-making to be better

understood, they could perhaps publish it retrospectively.

Chapter 3: Unconventional Policy and Broad Money

3.1. The Adoption of Unconventional Monetary Policy

3.1.1. Financial Crisis and Unconventional Monetary Policy

Under the policy reaction function and the transmission mechanism published on the official website of the Bank of England, the Monetary Policy Committee had adjusted the bank rate to a level of 5.75% in the fall of 2007 following a series of rises since 2003. As suggested in chapter 1, the interest rate adjustment is based on the projection of inflation 2 years ahead and the projection of output 1 year ahead. Though the global credit crisis had broken out in 2007, the MPC decided to raise the interest rate a little to 5.75% as the projections made at that time indicated a continuous growth of output and an inflation with upside risks.²⁸ The interest rate after that was not cut dramatically until the autumn of 2008 when the crisis intensified and it fell from 5% to 0.5% in the space of half year. The prospects for economic activity worsened for the following several years. In the inflation report released at the beginning of the big rate-cut, the Governor suggested that the economy had entered a recession and the forecasts of GDP and inflation were weaker than the previous projections. Under circumstances where the outlook for inflation had changed substantially, the MPC kept on cutting the interest rate until it reached 0.5% in March 2009. Monetary policy during this period was still being operated as in the previous years, that is in a forward-looking manner and targeting inflation by setting the interest rate. This strategy of monetary policy is commonly thought of as ‘conventional monetary policy’.

The interest rate had been close to the ‘zero lower bound’ at the beginning of 2009 when the prospects for GDP and inflation were still negative. In the inflation report of the BoE in February 2009, the forecast percentage increase in output had been negative and the forecast of inflation in two years’ time was under the target level of 2%.²⁹ Besides

²⁸ The press release from the Bank of England lists the reasons of interest rate decision. See <http://www.bankofengland.co.uk/publications/Pages/news/2007/070.aspx>

²⁹ This is partly because of the VAT cut

the UK, economic activity in other regions, such as the US and the Euro Area, was also low though their central banks had decreased their policy rates as well. At this stage, interest rates could not be adjusted further to encourage the medium term inflation in the light of the global recession and other actions were needed to supplement the conventional policy.³⁰ In March 2009, the MPC of the BoE announced its decision to introduce the ‘unconventional monetary policy’ of quantitative easing (QE): it cut the policy rate to what it believed was the minimum feasible of 0.5% and “also resolved to undertake further monetary actions, with the aim of boosting the supply of money and credit and thus raising the rate of growth of nominal spending to a level consistent with meeting the inflation target in the medium term”.³¹

The Federal Reserve also introduced quantitative easing at the start of 2009 by purchasing Treasury securities “to help improve conditions in private credit markets”, while an earlier paper by Bernanke and Reinhart (2004: 87) had referred to changing the size of a central bank’s balance sheet (i.e. QE) as “buying or selling securities to affect the overall supply of reserves and the money stock”. The Banque de France in its 2010 study identifies one category of non-conventional monetary policy measures as “achieving a massive increase in the quantity of money circulating in the economy. This is called ‘quantitative easing’” (Banque de France, 2010: 45).

3.1.2. Broad Money in Quantitative Easing

When the policy makers around the world took the decisions on quantitative easing, they were thinking not only of Japan’s deflation problem in the 1990s and 2000s and Japan’s first use of quantitative easing, but also of the role of monetary contraction in the Great Depression. Chairman Bernanke had of course studied that episode (see his 2004 book) and was familiar with the argument (which goes back to Friedman and

³⁰ The Committee considered a further reduction in the bank rate might have inverse impact on the economy. If the banks passed the cuts in bank rate to their deposit rates, they might reduce lending. And what’s more, sustained low interest rate may harm the functioning of money market.

³¹ Press statement 5 March 2009, available at <http://www.bankofengland.co.uk/publications/news/2009/019.htm>. See also the Minutes of the MPC meeting at <http://www.bankofengland.co.uk/publications/minutes/mpc/pdf/2009/mpc0903.pdf>.

Schwartz, 1960) that the money stock was allowed to fall too much in the early 1930s and this contributed to the depth and length of the depression. Governor King had earlier argued explicitly that it “is crucial to look at developments in quantities in the monetary area and credit conditions, as well as prices... My own belief is that the absence of money in the standard models which economists use will cause problems in the future...” (King, 2002: 172-3).

However, the two principal pieces of early research to have come out of the Federal Reserve and the Bank of England (BoE) on quantitative easing focused on the effects of QE on long-term interest rates, and made little reference to money or credit.³² Gagnon, Raskin, Remache and Sack (2010) used event study and time-series analysis and found that yields on US long term Treasury bonds fell in response to large scale asset purchases by 50-100 basis points (in the event study) or 38-82 bps (in the time-series analysis). Joyce, Lasoosa, Stevens and Tong (2010) also used event study and time-series analysis, and found falls in yields on UK gilts of 50-100 bps.³³ Moreover, these papers do not go on to link the fall in yields to the development of economic activity (or inflation).³⁴

This disconnect between the policy announcements of the Fed and the BoE and the main research coming out of these institutions is surely disturbing. The absence of money and credit from mainstream empirical research is clearly the result of the way

³² On the other hand a number of papers published in the Bank’s *Quarterly Bulletin*, including Bell and Young (2010) and Bridges, Rossiter and Thomas (2011), discussed the evolution of money and credit in some detail. See also the sections on ‘Money and asset prices’ of the various *Inflation Reports* over the period. I draw on this work below. The Bank’s view of the transmission mechanism (Benford, Berry, Nikolov, Young and Robson (2009) also sees a clear intermediate role for money in QE.

³³ Joyce et al. discuss QE as a swap between money and gilts in their section 6, but they do this only as an alternative way of estimating the effect on long term yields.

³⁴ On the other hand, a related paper which follows the effects through to the real economy is that by Lenza et al (2010), who investigate the effects of (non-QE) unconventional monetary policies in the euro area. They consider a ‘no-policy’ counterfactual scenario in which spreads between 3- and 12-month EURIBOR and the euro overnight index average EONIA remain the same as in October 2008, and a ‘policy’ scenario in which these spreads move as they did in fact move, over November 2008 to August 2009. In the policy scenario spreads are significantly lower. They then use these interest rate spreads to simulate in a large scale VAR model the development of variables including industrial production, unemployment, inflation, bank lending and money, under each scenario. Overall, the exercise seems to indicate that the policy measures mitigated the crisis and the recession.

macroeconomics has developed over the last two decades, with the New Keynesian and Dynamic Stochastic General Equilibrium models that came to be dominant including an interest rate but leaving no space for any monetary or credit aggregate, as in Woodford (2003). The main reasons for ignoring the aggregates are, first, that if money demand is a stable function of a small number of variables (as in Friedman, 1956) then data on money supply will not provide any information additional to that incorporated in data on the arguments of money demand, that is income, prices and interest rates; and, second, that the money supply is endogenously determined within the financial system and via its interactions with the real economy, through the kind of portfolio adjustment mechanisms first set out by Tobin (1963), so that it has no independent causal role.

A small number of economists have continued to argue that some attention at least should be paid to monetary aggregates. Laidler (2006: 158) in his review of Woodford's paper argued that Woodford's theory was "well adapted to teaching us how to sail in already calm monetary conditions, in fair fiscal weather and in the confined waters of a closed economy". And Goodhart (2007) argued that the relegation of money had gone too far, emphasizing the importance of supply-side (as opposed to demand-side) shocks to money and the possibility of shifts in banks' willingness to supply loans. More recently Driffill and Miller (2010) have used the model of Kiyotaki and Moore (2008) to underpin an analytical model in which liquidity constraints (which can be seen as a manifestation of financial crisis) turn out to have a large impact on economic activity.

This chapter asks whether broad money might have had independent causal effects in the current period and whether a stronger focus on it might not help us to understand QE better.³⁵ I firstly construct a simple SVAR model to estimate the response of inflation and output to a shock to broad money. This model has been widely used in recent work, and by doing so, I can get a general indication of impact of QE on economic activity. Then for further analysis, I use the once well-known flow of funds

³⁵ There is a parallel in intention between our work and that of Giannone et al. (2011), but they have the advantage of being able to use the 32-variable VAR model of Giannone et al. (2009) which includes monetary and credit aggregates as well as standard macro variables.

framework to discuss the mechanics of financial crisis, fiscal expansion and QE. In section 3.4.1 I look at the relevant data for the UK over the last 3-4 years. In section 3.4.2 I report the results of a simple reduced-form regression of the relationship between nominal spending growth and nominal money growth using interacted dummies for the crisis period. In sections 3.4.3 and 3.4.4 I illustrate the striking results of that regression by using appropriate counterfactuals to consider what they imply first for the contribution of the financial crisis to the path of spending in 2008-9, and then for the contribution of QE in 2009-10. Section 3.5 concludes by arguing that this investigation should be taken further by the introduction of monetary and/or credit aggregates in some form into existing large-scale macroeconomic models of the UK.

3.2. A Structural VAR Estimation of the Impact of QE

Although most empirical work on QE has focused on the impact on financial markets since the announcement of QE, there are several papers released after 2011 which have extended their estimate to the impact of QE on the macroeconomy. Bridges and Thomas (2012) used an aggregate co-integrated SVAR model to establish the impact of QE on asset prices and nominal spending. They assumed that QE brought about an 8% increase in broad money which should be considered as a shock to the money supply. This shock brought yields down around 150 basis points. And in their SVAR estimation, they found the peak effect of this 8% shock on output is around 2%, with an impact on inflation of 1 percent. Another important paper examining the macroeconomic impact of QE is Kapetanios et al (2012). They focused on the transmission channel through which asset purchase affected lower long-term interest rates. Then they used three different models (BVAR, MS-SVAR and TVP-SVAR) to estimate the impact of QE on inflation and output. They suggested a peak effect on real GDP of 1.5% and on CPI of 1.25%.

In this section, in order to have a general idea about the influence of QE on macroeconomic activity before the further analysis in section 3.3, I will use a simple Structural VAR model to estimate the impact. Drawing inspiration from the two papers above together with Dhar et al (2000), I construct a 4-variable simple SVAR. As the

purpose of this chapter is not to suggest a transmission channel, I don't include any financial market variables in the model as the two papers above did. The variables in my estimation are inflation (π), real GDP (y), bank rate (r) and real money (m), three of which are used in estimations of Taylor Rule reaction functions. The purpose of the estimation is to study directly the influence of monetary shocks on macroeconomic activity. The SVAR model can be expressed as:

$$Y_t = \alpha_1 Y_{t-1} + \alpha_2 Y_{t-2} + \dots + \alpha_p Y_{t-p} + \varepsilon_t \quad (3.1)$$

Where $Y_t = (\pi_t, y_t, r_t, m_t)'$

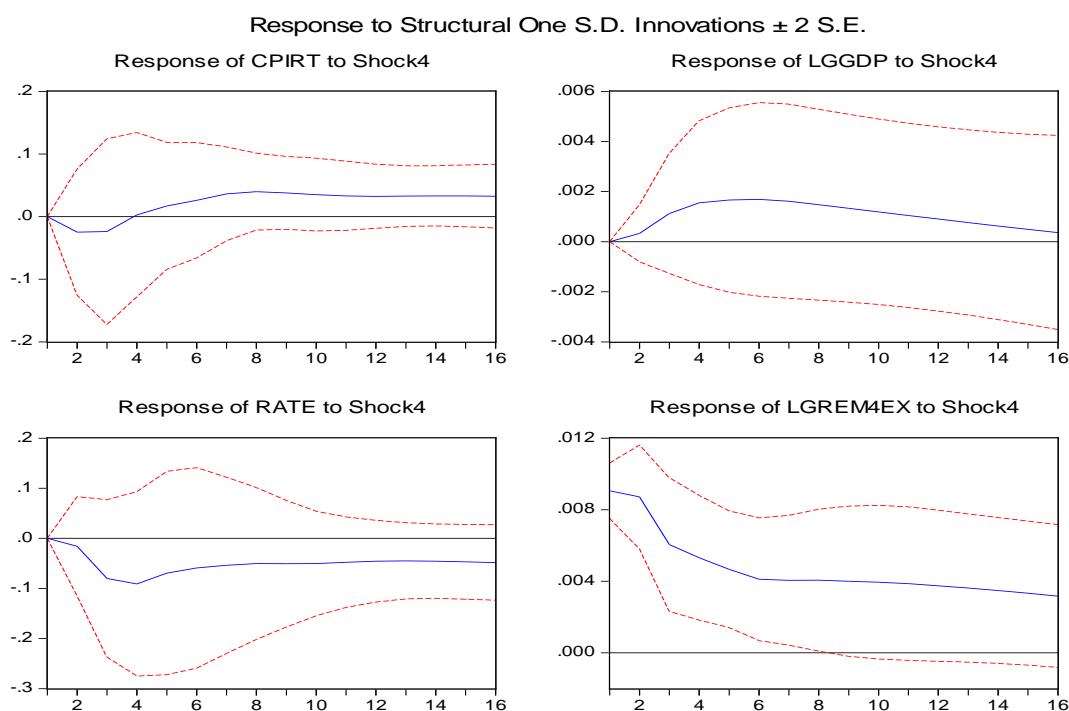
The shocks in the SVAR model in this section are all temporary shocks: a shock to inflation (μ_{UR}), an aggregate demand shock (μ_{AD}), a monetary policy shock (μ_{PL}) and a "QE-like shock" (μ_{QE}). The QE-like shock is created by Bridges and Thomas (2012), this shock by assuming that it does not have an instant impact on inflation and GDP or the short-term rate, but has an impact on money, long-term rates and the exchange rate. In my estimation here, as the exchange rate and long-term rate are excluded from the simple SVAR, I assume that the QE-like shock only has an instant impact on money. Because the bank rate has been restricted to the 0.5% level since 2009, and the timing assumption implies lags for the transmission to output and inflation, the QE-like shock has zero impact on the other three variables at the time when the shock happens. Following Dhar et al (2000), the other shocks are a monetary policy shock, an aggregate demand shock and an unrestricted shock. Under monetary policy shocks, money and Bank rate change immediately while output and inflation will change with lags. The aggregate demand shock can't impact inflation at the time of the shock. The unrestricted shock indicates that if there is a shock to inflation, all variables in the model will simultaneously react to it. Thus the short-run restrictions in SVAR could be shown as;

$$\begin{pmatrix} \pi \\ y \\ r \\ m \end{pmatrix} = \begin{pmatrix} * & 0 & 0 & 0 \\ * & * & 0 & 0 \\ * & * & * & 0 \\ * & * & * & * \end{pmatrix} \cdot \begin{pmatrix} \mu_{UR} \\ \mu_{AD} \\ \mu_{PL} \\ \mu_{QE} \end{pmatrix}$$

Where μ_{UR} =unrestricted shock, μ_{AD} =aggregate demand shock, μ_{PL} = monetary policy shock, and μ_{QE} = QE-like shock.

By choosing the smallest values of AIC and SC, I include three lags of variables in the model. Under this structure, no root lies outside the unit circle so the model satisfies the stability condition. The sample period is from the first quarter of 1994 to the end of 2010. The data for inflation is the change in the Consumer Price Index (CPI) rate (since the year before), the level of GDP is the log of GDP volume, the interest rate is Bank rate and money is defined as M4ex-M4 excluding intermediate OFCs (the Bank’s preferred measure of broad money outstanding) deflated by the GDP deflator.³⁶

Figure 3.1: Impulse responses to QE-like shocks (shock 4 in the graphs)



An impulse analysis is given in Figure 3.1. Figure 3.1 shows the responses of all

³⁶ Though the Bank of England prefers M4ex as a measure of broad money now, it only supplies the data of M4ex back to 1998. The spread between M4 and M4ex increased heavily after 2003Q4 so M4 is not a good measure of broad money though it has a longer data. Because the spread was stable between 1998 and 2003Q3 at around 4.6% , I took the average value of the spread in this period and, under the assumption that the same spread existed before 1998, constructed data for M4ex before 1998.

variables in the model to the QE-like shocks within the following 4 years. When the QE-like shock has one standard deviation, the real money immediately rises by 0.9%. This response decreases in the following periods until period 6 after which the response of the real money to the shock stays around 0.41%. Inflation starts to react to the shock after two quarters and has a positive response after 4 quarters. The peak positive effect of 4 basis points occurs two years after the shock. Though it is unclear why inflation decreases slightly at first, the response of inflation remains positive after one year. Real GDP responds to the shock with an increase which peaks at 0.16% in quarter 6. This increase gradually vanishes towards zero as the period gets longer. It is clear from the figure that GDP will return to its original level 4 years after the shock. The interest rate in this model has a negative response which lasts at least 4 years after the shock happens.

Except for the response of money growth, it is hard to reject the proposition that all other three responses are not significantly different from zero, since the red bands which represent 2 standard errors include zero. It seems that it is hard to get clear evidence of the impact of money growth change on the macroeconomy directly by using this simple VAR. However, the shape of the central estimates of the responses in Figure 3.1 are in line with the results in Bridges and Thomas (2012) which considered exchange rate, various yields and asset prices in the model. The response of GDP in that model also peaked after four quarters and disappeared in the longer term. So it is still worth calculating the cumulative response by the central estimates. Based on the estimation in Figure 3.1 and the data on broad money since the implementation of QE, I calculate an estimate of the impact of QE on output and inflation. Figure 3.2 shows the Bank of England's cumulative gilt purchases under the Asset Purchase Facility between March 2009 and January 2010. By the end of the exercise the asset purchases had reached the scheduled £200bn, which amounted to about 13% of M4ex in March 2009 and nearly 14% of nominal GDP in 2008. As this increase of 13% of broad money is accumulated quarter by quarter, the second and the third rows of Table 3.1 list the gilts purchased and the corresponding percentage change of M4ex. Considering the responses shown in

Figure 3.1, I estimate the impact on real GDP in 2010 is around 2.5% and the impact on inflation is 0.4%, as shown on the fourth and fifth rows of Table 3.1.³⁷

Table 3.1: The asset purchased and the sum effect on macroeconomic activity

	09Q1	09Q2	09Q3	09Q4	10Q1	10Q2	10Q3	10Q4
Gilt purchased	£17.24 billion	£84.31 billion	£54.606 billion	£33.8 billion	£10.225 billion	0	0	0
%of M4ex	1.14%	5.89%	4%	2.53%	0.76%	0	0	
Effect on GDP						2.3%	2.5%	2.5%
Effect on CPI						0.06%	0.3%	0.45%

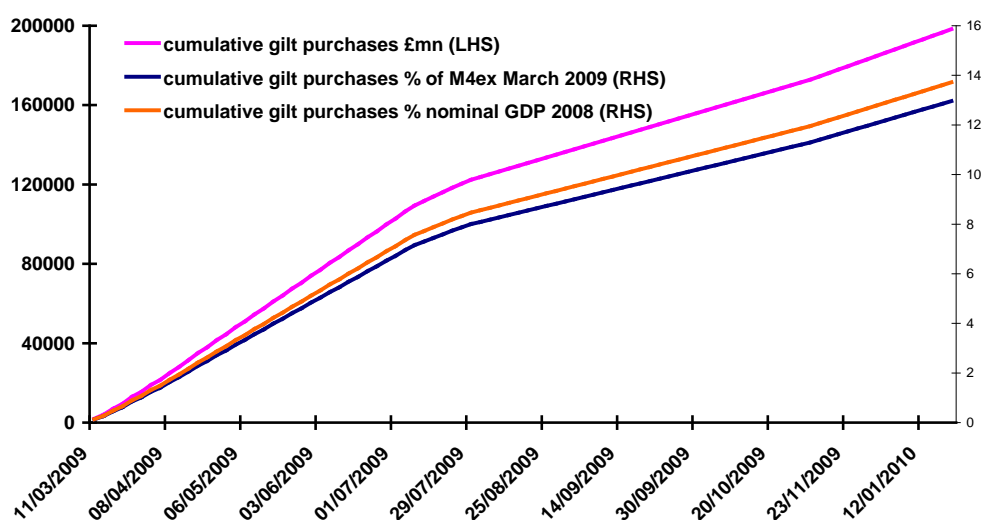
Compared with the results in Bridges and Thomas (2012), the estimated impact on real GDP is a little higher while the impact on inflation is lower. But this gap is not big. Especially when Bridges and Thomas (2012) take uncertainty into consideration, my estimations³⁸ fall in the range of their estimations.³⁹

³⁷ The way I calculate the impact of QE for one quarter is to sum up the effects brought by the continuous asset purchases before that quarter. Take 2010Q2 as an example. The effect on GDP in 2010Q2 from the 1.14% increase in M4ex in 2009Q1 which is five quarters before is $1.14 \times 0.1688 = 0.19\%$. 0.1662 is given by the impulse response table. And the effect from 5.89% increase in M4ex in 2009Q2, 4% in 2009Q3, 2.53% in 2009Q4, 0.76% in 2010Q1 are 0.98%, 0.62%, 0.28% and 0.03% respectively. Sum them together, I got the effect on GDP in 2010Q2 is around 2.3%.

³⁸ The estimation of the impact on inflation in my SVAR model actually peaks in 2011 which is not shown in the table. It's value is 0.6%.

³⁹ Bridges and Thomas (2012) produced estimates not only from their preferred model but also from sectoral models with uncertainty. In their table 3 on p39, they give the estimation and the range of the impact on GDP as from 0.75% to 3.25% and the range of the impact on inflation is from 0.5% to 2.25%.

Figure 3.2: Gilt purchases by BoE under APF



This central estimation of a simple SVAR suggests how much macroeconomic activity would react to an exogenous shock to broad money. It indicates that QE's influence is greater on GDP than on inflation and that the impact peaks in the sixth quarter. However, compared with other VAR estimates, it suffers the drawback that the estimates are insignificantly different from zero. It might be because the SVAR model is constructed under the consideration of interactions among variables but the fact is that money growth during the crisis period is only influenced by the exogenous QE-like shock and has little effect from other variables in the VAR. It is impossible to assess clear counterfactuals by using this SVAR model. What's more, it can't show the responses of every sector in the economy when shocks happened or any possible offset raised by those sectors to QE's influence on broad money. The purpose of this chapter is not to compare different models or equations but to see if there is support for the goal pronounced by the BoE. Thus the estimated impact above needs support by further analysis. In the following sections, the mechanics of the shocks are explained and a naive reduced-form regression is used to indicate the impact.

3.3. The Mechanics of Crisis and Quantitative Easing

As the a number of articles I mentioned in the last sections explored the effects of the crisis and then of QE through the counterparts of broad money, I will draw on their insights in what follows, but I first present a simple analysis of the ‘mechanics’ of financial crisis and QE in terms of a flow of funds matrix (Table 3.2) of the kind which used to be included in undergraduate macro textbooks (e.g. Artis and Lewis, 1991; Cobham, 1998) but is not generally familiar today.

In Table 3.2 the columns represent different sectors of the economy: government, central bank, foreign, private non-financial (firms and households), and private financial (banks); while the rows represent first the financial surplus/deficit (net borrowing) of each sector (from the national income accounts) and then the changes in assets (positive) and in liabilities (negative) for each financial claim, e.g. deposits, government securities. Thus the columns show the balance sheet constraints for each sector, while the rows show the supply = demand conditions for each claim: each column and each row must sum to zero. In this simple presentation there are many assumed simplifications. For example, the central bank and the private financial sector are assumed to have no (physical) investment or saving (out of income); government securities are held only by domestic agents; non-financial corporate equity and bonds are issued and held within the private non-financial sector (so they are not visible); and contingent liabilities (derivatives) are not shown because they are off balance sheet.⁴⁰ Moreover, what the table shows is essentially identities rather than behaviour. However, this framework is useful because it obliges us to think through the ramifications of any change: a change in one sector’s acquisition of a financial claim must involve some offsetting change in that column and in that row, and typically some further changes as well.

The identities in the table can be manipulated (and this was often the main purpose of

⁴⁰ The one significant difference from the table in Cobham (1998) is that the government and central bank are separated here, in the light of the modern focus on central bank independence and the need to locate QE within that context.

the exercise in the past) so as to derive the counterparts to broad money growth:⁴¹

$$\Delta M_s = \text{DEF} - \Delta \text{GD}_{\text{nf}} + \Delta A - \Delta \text{NDL} + \Delta \text{RES}$$

where M_s is broad money supply, DEF is the government's budget deficit, GD_{nf} is the amount of government debt held by the private non-financial sector, A is banks' lending (advances) to the private non-financial sector, NDL is banks' non-deposit liabilities (mainly equity issued by the banks) and RES is the central bank (CB)'s foreign exchange reserves. This is broadly the credit counterparts to monetary growth as identified, for example, in Table A3.2 of the Bank of England's *Bankstats*. But the flow of funds as a whole goes beyond that insofar as it represents the balance sheet constraints of the non-bank sectors as well.

I now consider through this framework the proximate effects of a number of exogenous changes, as summarized in Table 3.3; the changes discussed are restricted to simple cases where there are 'single-factor' offsets, and the analysis focuses on first-round effects and ignores subsequent portfolio adjustments (many of which take place within the private non-financial sector). I start with more simple cases and build up to more interesting ones.⁴² The simplest change (row 1 of Table 3.3) is an increase in the central bank's lending to the commercial banks (CBL): here the CB has a rise in its assets together with a rise in its liabilities (in the form of banks' reserves at the CB), while the banks have a rise in their liabilities (CBL) and a rise in their assets (R). The result is that M_s is unchanged (neither notes and coin nor banks' deposits are affected) but high-powered money H increases.

⁴¹ To derive this, write each of the private non-financial column, the financial deficit row and the overseas column as equations:

$$(\text{I-S}) + \Delta \text{D} + \Delta \text{NDL} + \Delta \text{C} + \Delta \text{GD}_{\text{nf}} = \Delta A + \text{K} \quad [\text{A}]$$

$$\text{DEF} + (\text{X-Z}) + (\text{I-S}) = 0 \quad [\text{B}]$$

$$(\text{X-Z}) + \text{K} = \Delta \text{RES} \quad [\text{C}]$$

then substitute for I-S in [A] from [B], and for X-Z from [C] and use the definition $\Delta M_s = \Delta \text{D} + \Delta \text{C}$.

⁴² In the discussion that follows I talk of rises or falls in assets and liabilities, but strictly the changes are rises or falls in the flows into assets and liabilities, i.e. changes relative to whatever else is happening.

Table 3.2: Simplified flow of funds matrix

	government	central bank	overseas	private non-fin	private financial	total
1) fin def	G-T		X-Z	I-S		0
2) deposits				ΔD	$-\Delta D$	0
3) non-deposit liabilities				ΔNDL	$-\Delta NDL$	0
4) high-powered money		$-\Delta H$		ΔC	ΔR	0
5) government securities	$-\Delta GD$	ΔGD_{cb}		ΔGD_{nf}	ΔGD_f	0
6) CB lending to banks		ΔCBL			$-\Delta CBL$	0
7) domestic lending				$-\Delta A$	ΔA	0
8) foreign lending		ΔRES	$K - \Delta RES$	$-K$		0
total	0	0	0	0	0	

Notes: G-T, X- Z (Z for imports) and I-S are the standard sectoral financial deficits as in the national income accounts; D and NDL are bank deposits and bank non-deposit liabilities respectively; H, C and R are high-powered money, notes and coin in circulation and banks' reserves at the central bank; GD, GD_{cb} , GD_{nf} and GD_f are the stock of government debt (securities) in existence, and the amounts held by the central bank, private non-financial and private financial sectors respectively; CBL is short term lending from central bank to commercial banks, i.e. 'money market assistance'; A is bank lending (advances); K is capital inflows, and RES is the foreign exchange reserves. The change in high-powered money is equal to the change in notes and coin in circulation (ΔC) plus the change in banks' reserves at the central bank (ΔR). The change in broad money is equal to the change in notes and coin in circulation (ΔC) plus the change in deposits (ΔD).

Row 2 of Table 3.3 shows the effect of the issuance of new equity and bonds by the banks: the banks incur more non-deposit liabilities but the payments for the new equity and bonds from the private non-financial sector reduce the amount of that sector's bank deposits. The banks end up with less deposits but more non-deposit liabilities, while the private non-financial sector ends up with less deposits but more non-deposit claims on the banks. Thus M falls but H is unchanged

Row 3 considers the case of banks' purchases of government securities (perhaps in order to increase their holdings of liquid assets) from the private non-financial sector. Here the two sectors swap government paper and deposits, in the opposite direction to the previous case. M rises but H is unchanged.

Row 4 treats the case of a conventional fiscal expansion financed by a bond issue: there is an increase in the government's budget deficit $G-T$ to which I assume there a corresponding fall in the private sector's deficit $I-S$ (and no change in the current account $X-F$), together with an issue of bonds by the government. In this simple case the private non-financial sector 'spends' the additional resources from its increased savings/reduced investment on buying the new government bonds. There is no change in M_s or H .

Row 5 considers a 'pure' financial crisis in which banks reduce their lending to the private non-financial sector. For both sectors the reduction in bank lending is balanced by a reduction in deposits. The result is that M_s falls (because D falls) while H is unchanged.

Row 6 is for 'pure' quantitative easing: the CB goes into the market and buys government bonds from the private non-financial sector. By the time the CB's cheque has passed through the payments system, this brings about an increase in both the deposits of the private non-financial sector and the reserves of the commercial banks. For the CB the rise in its assets (increased bond holdings) is balanced by the rise in its liabilities in the form of banks' reserves, for the banks the rise in their assets (reserves) is balanced by a rise in their deposit liabilities, and for the private non-financial sector the fall in bond holdings is balanced by a rise in another asset, their bank deposits. The result is that M and H both rise.

Row 7 combines a financial crisis/fall in bank lending (as in row 5) with a fiscal expansion (as in row 4) of the same magnitude. The private non-financial sector ends up with more bonds (to the extent of the fall in its financial deficit), less loans and less

Table 3.3: Effects on the flow of funds

	Exogenous change	proximate ramifications	effect on Ms	effect on H
1	standard CB refinancing of banks: increase in CBL	$\Delta CBL \uparrow, \Delta H \uparrow, \Delta R \uparrow$; banks get increased liability (CBL) but increased asset in form of additional reserves at CB (R)	no change	rise
2	issuance of new equity and bond by banks, bought by private non-financial sector	$\Delta NDL \uparrow, \Delta D \downarrow$; private non-financial sector has less bank deposits but more bank paper, banks have less deposit but more non-deposit liabilities	fall	no change
3	banks buy government bonds (to improve own liquidity) from private non-financial sector	$\Delta GD_{nf} \downarrow, \Delta GD_f \uparrow, \Delta D \uparrow$; banks have more government bonds but more deposit liabilities, private non-financial sector has less bonds but more deposits	rise	no change
4	fiscal expansion (with equivalent fall in private sector financial deficit) financed by bond issue bought by private non-financial sector	$G-T \uparrow, I-S \downarrow, \Delta GD \uparrow, \Delta GD_{nf} \uparrow$; private non-financial sector buys newly issued bonds with its extra financial resources	no change	no change
5	'pure' financial crisis: banks reduce their lending	$\Delta A \downarrow, \Delta D \downarrow$; equivalent reduction in bank lending and deposits affecting both financial and non-financial sectors (in opposite ways)	fall	no change
6	'pure' QE: CB purchases government bonds from private non-financial sector	$\Delta GD_{cb} \uparrow, \Delta GD_{nf} \downarrow, \Delta D \uparrow, \Delta R \uparrow$; rise in private non-financial sector's deposits (balancing fall in its bonds), rise in banks' reserves at CB (offsetting rise in their deposit liabilities)	rise	rise
7	financial crisis plus fiscal expansion financed by bond issue bought by private non-financial sector	$G-T \uparrow, I-S \downarrow, \Delta GD \uparrow, \Delta GD_{nf} \uparrow, \Delta A \downarrow, \Delta D \downarrow$; private non-financial sector has more bonds (to the amount of the fall in I-S), less loans and less deposits [sum of rows 4 and 5]	fall	no change
8	financial crisis plus QE: bank lending falls but CB buys more bonds to same extent	$\Delta A \downarrow, \Delta GD_{cb} \uparrow, \Delta GD_{nf} \downarrow, \Delta R \uparrow$; private non-financial sector has less loans but also less bonds and its deposits remain unchanged, banks have less loans but more reserves at CB [sum of rows 5 and 6]	no change	rise
9	fiscal expansion plus QE: government issues new bonds which are then purchased by CB	$G-T \uparrow, I-S \downarrow, \Delta GD \uparrow, \Delta GD_{cb} \uparrow, \Delta D \uparrow, \Delta R \uparrow$; private non-financial sector has lower financial deficit and higher deposits, banks have rise in reserves [sum of rows 4 and 6]	rise	rise

deposits. The result, which is the sum of the results for rows 4 and 5, is that M falls and H is unchanged.

Row 8 combines the financial crisis with QE (as in row 6) of the same magnitude: here banks' lending falls but the CB steps in to buy government bonds, and its purchase of bonds from the private non-financial sector offsets the impact of the fall in banks' lending on the private non-financial sector's bank deposits. For the banks there is a fall in one asset (loans) offset by a rise in another (reserves at the CB). The overall effect (the sum of those in rows 5 and 6) is that M is unchanged but H rises.

Finally, row 9 combines fiscal expansion with QE of the same magnitude. Here the government issues bonds to cover its increased budget deficit, and these bonds are in effect bought by the private non-financial sector (the independent CB is not allowed to participate in the primary government debt market) but then sold immediately to the CB. Thus the private non-financial sector, which has a reduced financial deficit (corresponding to the increased government budget deficit) ends up with a rise in its deposits, while for the banks the increase in deposit liabilities is balanced by a rise in reserves at the CB. In total (combining the results of rows 4 and 6), M rises (because deposits rise) and H rises (because banks' reserves rise). This is, in effect, the standard case of a monetary-financed fiscal expansion.

The most important point to take from the present discussion is that QE raises the money supply, either absolutely (rows 6 and 9) or relative to what would have happened otherwise (row 8). On the other hand, banks' issues of new equity tend to reduce money, while banks' acquisitions of government debt tend to increase it.

3.4. An Analysis of Broad Money and Its Influence

3.4.1. Monetary growth in the UK 2007-10

In this section I will try to highlight the large developments in financial flows since

2007.⁴³ Figure 3.3 shows the trend decline in the velocity of broad money (measured as quarterly nominal GDP divided by M4ex), which was then reversed from 2009 Q2. The lines for nominal income and broad money growth (since four quarters before) make clear that the last part of the decline reflected a faster fall of nominal income than of broad money from mid-2008, while the reversal of the decline reflected the rebound of nominal income growth; broad money growth on this four quarter basis did not go negative, and began to rise again after 2010 Q1.

Figure 3.3: Velocity, nominal income growth and broad money growth

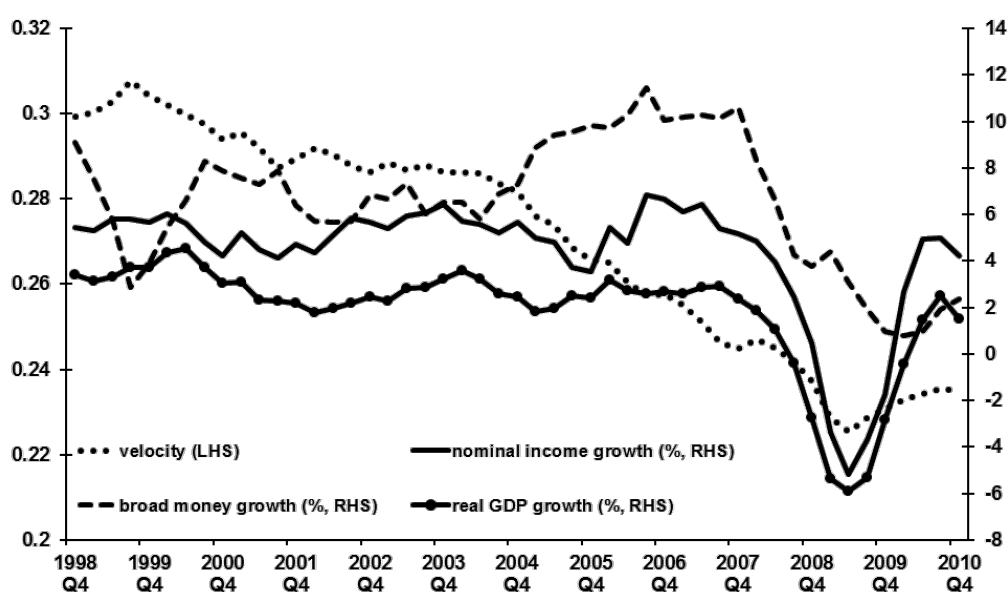


Figure 3.4 shows the four quarter growth rates of M4ex and M4ex lending. Between mid-2005 and end-2007 M4ex grew at around 10%, while M4ex lending growth was initially higher but started falling in mid-2007. The growth of both series fell sharply in 2008 and 2009 to below 2%. Lending recovered slightly in late 2009/early 2010 and then declined further, while M4ex growth rose gently from 2010Q1.

⁴³ The monetary data are from the Bank of England's interactive statistical database, and other data from the Office of National Statistics and *International Financial Statistics*.

Figure 3.4: Four quarter changes in M4ex and counterparts (% of M4ex)

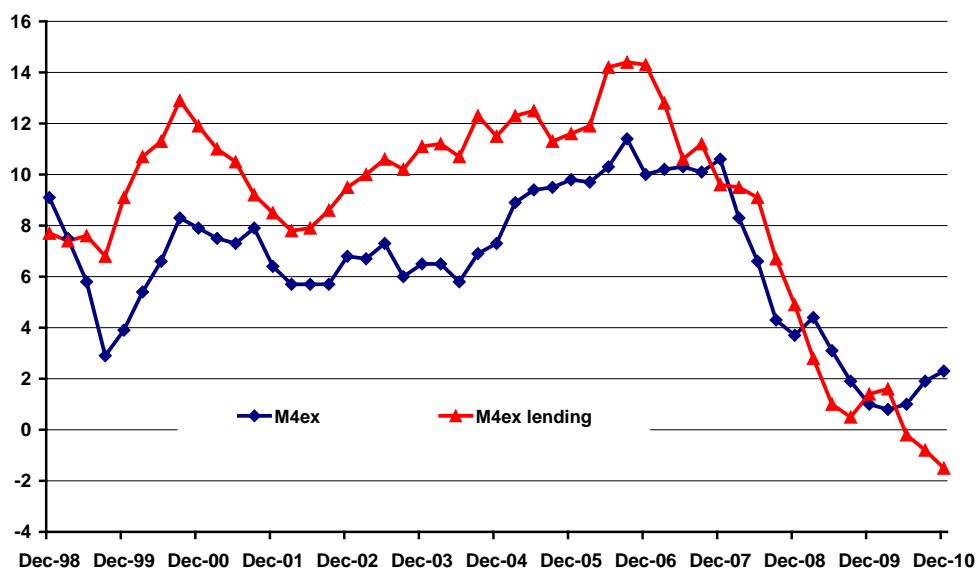


Figure 3.5: M4ex and counterparts, four quarter changes (£ mn)

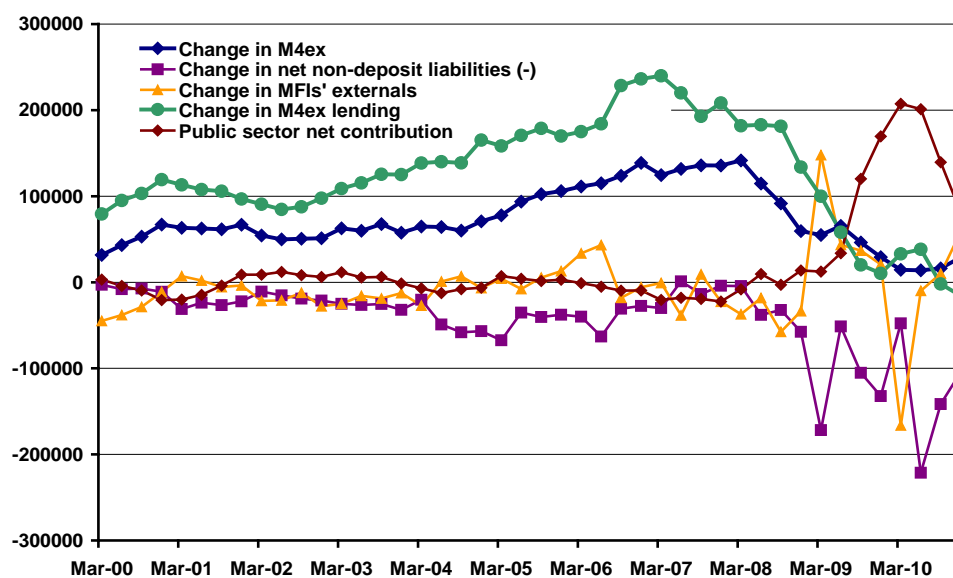


Figure 3.5 shows four quarter growth changes for M4ex, M4ex lending and the other counterparts. Net sterling lending to the public sector by monetary financial institutions (MFIs), where MFIs include the Bank of England so that this includes asset purchases (QE), is essentially the government's deficit minus what it borrows from the private and

overseas sectors. This was close to zero up to mid-2009, when it rises very sharply, peaking in the first half of 2010 at a level comparable to that of M4ex lending in 2006-08 and exceeding total monetary growth in that period. The change in MFIs' externals (a heterogeneous category which includes central bank and commercial bank external and other foreign currency transactions) was low in the early years but then fluctuates widely in both directions in 2009-10. The change in banks' net non-deposit liabilities (a negative contribution to monetary growth, officially referred to as the change in MFIs' net sterling assets) was low in the early years but much larger and more erratic in 2009-10.

Figure 3.6: Financial surpluses/deficits by sector (% of GDP)

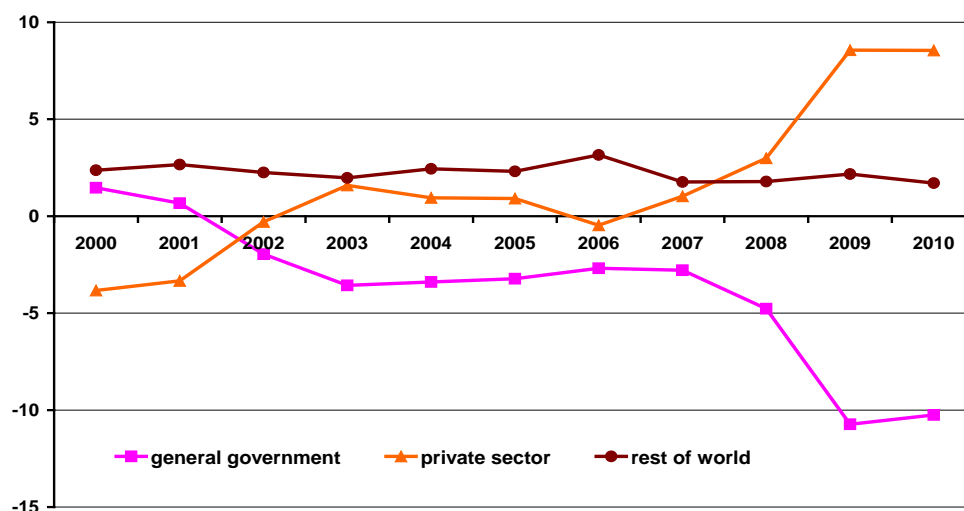
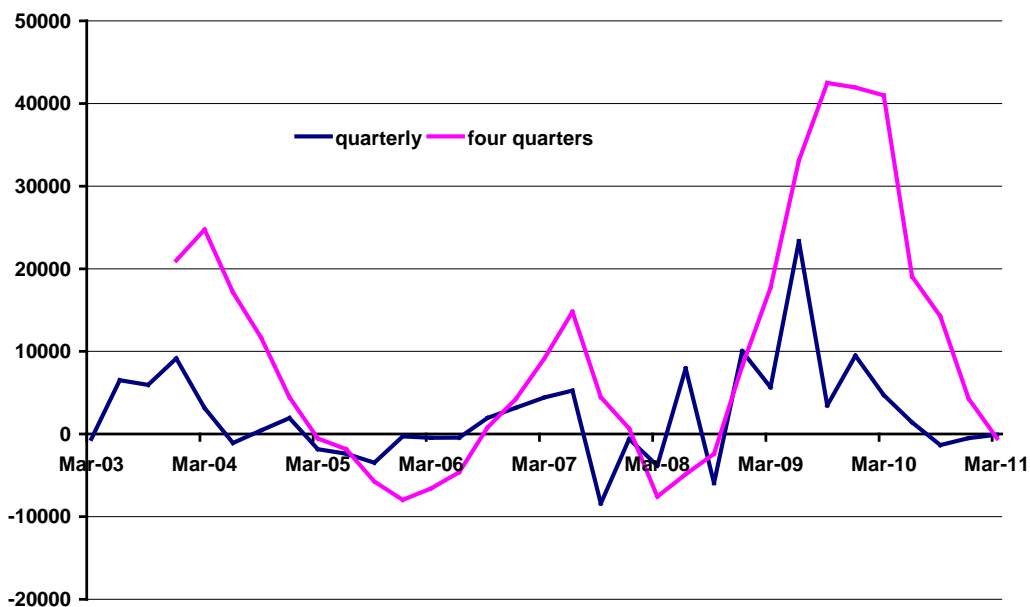


Figure 3.6 shows the financial surpluses/deficits of different sectors. In the early years the foreign sector has a consistent surplus (i.e. there is a current account deficit) and that continues with little change over 2008, 2009 and 2010. On the other hand the general government's deficit increases in 2008 and even more strongly in 2009, and falls slightly in 2010. The private sector has corresponding movements in its financial surplus; disaggregated data make clear that the main changes arise in the household sector, whose surplus increased very strongly in 2009, while non-financial and financial corporations experienced a rise and a fall respectively in 2010.

Finally, Figure 3.7 shows new issuance by private non-financial corporations (quarterly and over the four preceding quarters). The series fluctuates widely but it is clear that there were exceptional levels of issuance in 2009-10.

Figure 3.7: Issuance by private non-financial corporations



The main point that emerges from this discussion is that the fiscal expansion, the financial crisis (in terms of its impact on bank lending) and QE are all substantial and in some sense exogenous changes to the counterparts of broad money growth over 2008-10. The fiscal expansion clearly originates outside the monetary sphere, in the combination of the financial crisis, the sharp cyclical downturn and the measures taken to mitigate the recession by the Labour government. The financial crisis, with the problems of bad debts, on the one hand, and the freezing of the interbank market, on the other, led to a very sharp fall in bank lending: the careful examination by Bell and Young (2010) of the balance between credit supply side factors and loan demand factors finds that credit supply effects were dominant.⁴⁴ And QE itself was the result of a policy

⁴⁴ More precisely they conclude that “the evidence discussed in this article suggests a significant role for a persistent tightening in the supply of credit, independent of changes in credit quality and Bank Rate... Credit demand is also likely to have weakened during the recession...” (Bell and Young, 2010: 319). See also the study by Aiyar (2011) on the transmission of shocks to banks’ external funding through to their domestic UK lending.

decision taken by the MPC in the light of the crisis and the recession. Moreover, these changes are substantial enough not to be washed away in the short term through the usual adjustment mechanisms that allow monetary growth in more tranquil periods to be reasonably viewed as essentially endogenous.

This suggests that it would be useful to investigate whether I can use money and credit directly (in a reduced form equation) to analyse the course of UK GDP over the crisis. This would link the monetary developments to GDP in a way that the popular work on the effect of QE on long-term interest rates is unable to do. If a clear relationship is found this might make it possible to get a better grip of what would have happened to income in the absence of the financial crisis, and then in the absence of QE, by simulating the effects of counterfactual levels of monetary growth. In such an exercise it will be crucial to identify the appropriate counterfactual levels of monetary growth, taking account of the various potential offsets highlighted by Bridges et al. (2011): issuance by banks (affecting NDLs); banks' acquisitions of government debt (affecting MFIs' net lending to the public sector); and issuance by PNFCs, which may affect the demand for bank lending. First, however, examine the relationship between nominal spending growth and broad money growth.

3.4.2. The relationship between nominal spending growth and broad money growth

In this part I am going to investigate whether it is possible to explain the four-quarter growth rate of nominal GDP (the growth since four quarters before) on the basis of the four quarter growth rate of nominal money and other variables. I use four quarter growth rates in order to concentrate on 'medium term' effects and to abstract from short run noise.⁴⁵ Given that there is no obvious up-to-date reduced-form (or structural) model that I can pluck off the shelf to analyze this relationship, I approach it as follows. First, I draw on the forward-looking Taylor rule literature in choosing as regressors the variables typically used to forecast inflation and the output gap in standard GMM

⁴⁵ This also means that for the monetary data, where the seasonal adjustment procedures are still under discussion (Hussain and Maitland-Smith, 2010; Gilhooly and Hussain, 2010), I can reasonably use non-adjusted data.

estimations (see, for example, Clarida, Galí and Gertler, 1998), together with the nominal money growth rate. Second, I use the automatic econometric model selection procedure within PC-Give (formerly known as PC-GETS) to select the variables and the lags.

The measure of broad money is the Bank of England's recently introduced preferred measure, M4 excluding intermediate OFCs. This measure is only available since 1997 Q4, so I use the four-quarter growth rate of M4 as broad money growth before 1998 Q4. Figure 3.3 above shows the four quarter growth rates of nominal GDP and nominal money on this basis, together with the corresponding growth rate for real GDP. The independent variables are lagged nominal GDP growth, the annual growth rate of the world commodity price index, Bank Rate and nominal money growth. I consider up to 4 lags of each variable.⁴⁶

Since, as set out in the previous section, there is a suspicion that money may have been subject to extraordinary supply-side shocks in the last few years which might have changed the underlying relationships, we estimate this equation with interacted dummy variables for M4 growth and Bank rate: the dummy is defined as zero up to 2007 Q2 and 1 thereafter, and it is interacted with each of the four lags of these two variables.

The results of the regression are reported in the first column of Table 3.4. For the period as a whole, the automatic selection programme in PC-Give selects only the lagged dependent variable (lagged one period), nominal money growth (lagged three periods) with a rather small but significant coefficient, and commodity price inflation (lagged three periods), but not Bank Rate. However, the interacted dummy variables covering only the period from 2007 Q3 turn out to be very important: money growth (lagged two periods) has a significant coefficient of 0.70, and Bank Rate (lagged four periods) has a significant coefficient of -1.49. This coefficient on monetary growth is less than the 1 that might be expected from a simple quantity theory model (with constant velocity),

⁴⁶ I also experimented with US and euro area output gaps, but this did not produce satisfactory results.

but given the medium rather than long-term focus of the analysis it is impressively large. The coefficient on lagged Bank Rate is also strikingly high: it implies that a rise of 1% in Bank Rate leads in four quarters to a 1.49% fall in the rate of nominal GDP growth. The lags – given that money growth is since four quarters before – are broadly consistent with a priori expectations and, in the case of Bank Rate, with the Bank of England’s BEQM model.

The exercise is repeated in equation [2] for real GDP growth against real M4 growth. The latter is calculated using the GDP deflator, so the conversion is the same as for nominal GDP, but the other variables – commodity price inflation and Bank Rate – are unchanged between the regressions. The results are broadly the same. Here a second term in GDP growth (lagged four periods) is significant, and Bank Rate has a small but significant negative coefficient for the period as a whole. For the later period the interacted variables for money growth and Bank Rate both have smaller (than in [1]) but still highly significant coefficients.

These results were obtained from a naïve reduced form single-equation regression, which does not consider directly, for example, variables representing world economic activity or domestic fiscal policy and in which the lagged dependent variable is very important. However, the fact that the same broad pattern of results – small roles for Bank rate and money growth in the 1994-2007 period, but negative and significant coefficients on Bank rate and positive and significant coefficients on money growth in the later period – is found even if real GDP growth is made dependent on nominal money growth,⁴⁷ suggests that the finding is robust.

Overall, these results are consistent with the proposition that money has a significant role in explaining nominal spending growth in the periods which include the crisis and QE, but little such role in the tranquil pre-crisis period; and they are consistent with

⁴⁷ In this case there is a significant positive coefficient on Bank Rate for the overall period, but this is more than offset by significant negative values on the interacted dummy variables for Bank Rate (lagged two and four periods), and there is a significant positive coefficient on nominal money of 0.56.

Goodhart's (2007) argument that money may sometimes provide no additional useful information beyond that provided by inflation, output and interest rates, but in other periods money might tell us more, so that in general it should be monitored rather than ignored. In the next two sections I use the results of regression [1] to illustrate the magnitude of the impact monetary developments might have had on the economy, first for the downturn in bank lending in the crisis period of 2007-8 and then for the QE period of 2009-10.

Table 3.4: PC-Give autometrics estimation

Dependent variable: nominal GDP growth / real GDP growth

Sample period: 1994 Q1 to 2010 Q4

	[1]: nominal	[2]: real
Constant	2.29* (0.32)	1.31** (0.13)
GDP growth (-1)	0.51** (0.06)	0.79** (0.05)
GDP growth (-4)		-0.21** (0.03)
M4 growth (-3)	0.07* (0.03)	0.07* (0.03)
Bank Rate (-3)		-0.01** (0.004)
commodity price inflation (-2)		-0.01** (0.003)
commodity price inflation (-3)	-0.01** (0.004)	
M4growth (-2)*dum	0.70** (0.11)	0.47** (0.06)
Bank Rate (-4)*dum	-1.49** (0.18)	-0.74** (0.08)
Adjusted R ²	0.94	0.97
AR 1-5 test: F(5,57)	0.83090 [0.5331]	0.98108 [0.4373]
ARCH 1-4 test: F(4,60)	0.85417 [0.4967]	0.28612 [0.8859]
Normality test: Chi ² (2)	1.6718 [0.4335]	2.2232 [0.3290]
Hetero test: F(10,57)	2.5113 [0.0141]*	0.49697 [0.8850]
Hetero-X test: F(20,47)	1.5412 [0.1118]	0.57136 [0.9130]
RESET23 test: F(2,60)	1.5422 [0.2223]	1.6169 [0.2070]
AR 1-5 test: F(5,57)	0.83090 [0.5331]	0.98108 [0.4373]

Notes: growth of GDP or money is growth since four quarters before; equation [1] has nominal GDP growth as the dependent variable and nominal M4ex growth among the independent variables, equation [2] has real GDP growth as the dependent variable and real M4 growth among the independent variables; standard errors are in brackets; ** significant at the 1% confidence level; * significant at the 5% confidence level.

3.4.3. The effect on nominal income of the collapse of bank lending

I have already referred to the work of Bell and Young (2010), which found that there were significant supply-side factors in the downturn of bank lending to the private non-financial sector during the crisis. On that basis I suggest that an appropriate counterfactual A for what would have happened if there had been no financial crisis is that (nominal) M4ex lending would have continued through 2008 to 2009 Q4 at a 'normal' rate. Given that the evolution of M4ex over this period was dominated by and very close to that of M4ex lending (see Figure 3.3), I make this operational by simply assuming that the four quarter growth rate of M4ex does not fall below its average of 6.48% in 1998-2004 (which omits the period of faster growth in 2005-7). Thus on counterfactual A M4ex growth in 2008 Q1 is at the historical rate of 8.3% and in the following seven quarters it is 6.48%, as against the historical values of 6.6, 4.3, 3.7, 4.4, 3.1, 1.9, 1.0 and 0.8%. The actual and counterfactual paths for the four quarter growth rate of nominal money are shown in Figure 3.8. I then use the coefficient estimates from regression [1], the predicted values of the lagged growth rate, the counterfactual values for money growth and the actual values of commodity price inflation and Bank Rate, to calculate what the nominal GDP growth rate would have been under the counterfactual rate of money growth.

Table 3.5 gives the definition of the counterfactual and Figure 3.9 shows the actual path of the growth rate, and that predicted under counterfactual A (with the actual values of the independent variables up to 2008 Q1). It suggests that nominal spending growth would have been much higher if bank lending had not collapsed in the way that it did during the financial crisis: growth falls to a low of only -1.8% in the first half of 2009, as opposed to the actual trough of -5.5%, and by the end of 2009 it is picking up strongly. The high rates of growth reached in 2010 also reflect the cuts in Bank Rate in 2008 Q4 and 2009 Q1 (which might not have been needed if the financial crisis had not occurred). For this reason amongst others the counterfactual should be regarded as suggestive rather than a precise estimate.

Table 3.5: The counterfactuals

	purpose of counterfactual	implementation
A	to identify broad money growth in absence of financial crisis-induced cut in bank lending	broad money growth does not fall below its average for 1998Q4 to 2004Q2, i.e. 6.48%
B	to identify broad money growth in absence of quantitative easing	broad money level set equal to actual minus cumulative asset purchases under APF
C	to identify broad money growth in absence of QE but taking account of offsets from (a) rise in non-deposit liabilities (\Rightarrow $M_s\downarrow$) and (b) banks' purchases of public sector debt (\Rightarrow $M_s\uparrow$)	broad money set equal to actual plus excess of change in MFIs' net sterling assets (over average for 1997Q4-2007Q4) minus excess of MFIs' lending to public sector (over average for 1997Q4-2007Q4)
D	to identify broad money growth in absence of QE but taking account of offsets from (a) rise in non-deposit liabilities (\Rightarrow $M_s\downarrow$), (b) banks' purchases of public sector debt (\Rightarrow $M_s\uparrow$) and (c) increased issuance by PNFCs (\Rightarrow bank lending \downarrow and $M_s\downarrow$)	broad money set as in counterfactual C plus excess of PNFCs' issuance (over average for 2003Q1-2008Q4)

Note: the offsets are calculated from 2009 Q1 to the end of 2010, except for that for the non-deposit liabilities which starts in 2009 Q2 (because there are very high and largely offsetting variations in that series for 2008 Q4 and 2009 Q1, and given that QE started only in March 2009 it is unlikely that significant QE-related issuance by banks occurred in 2009 Q1).

Figure 3.8: Money growth under counterfactual A

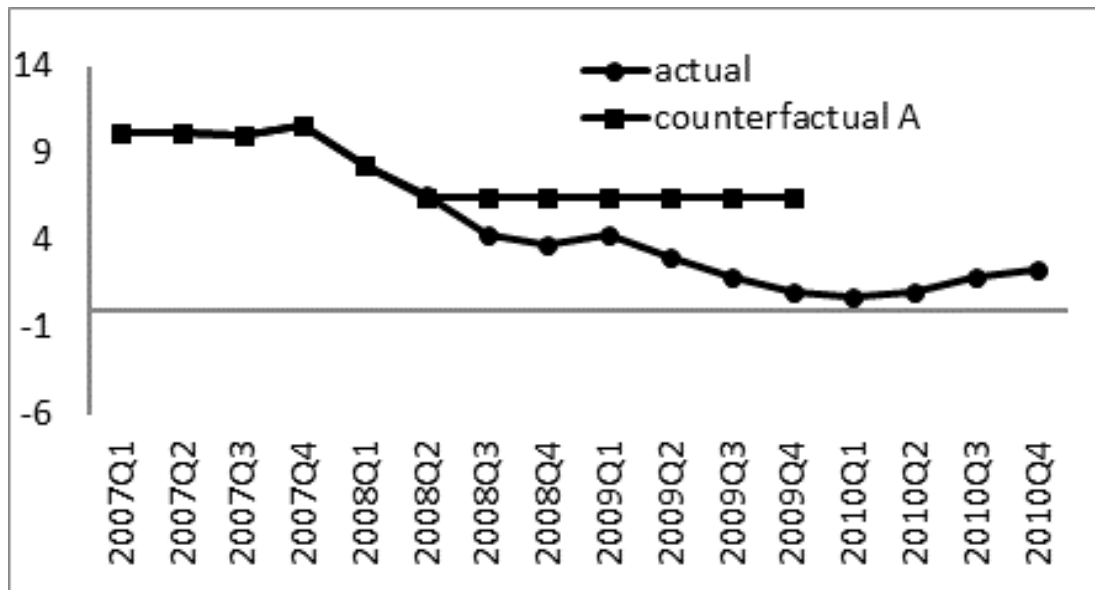
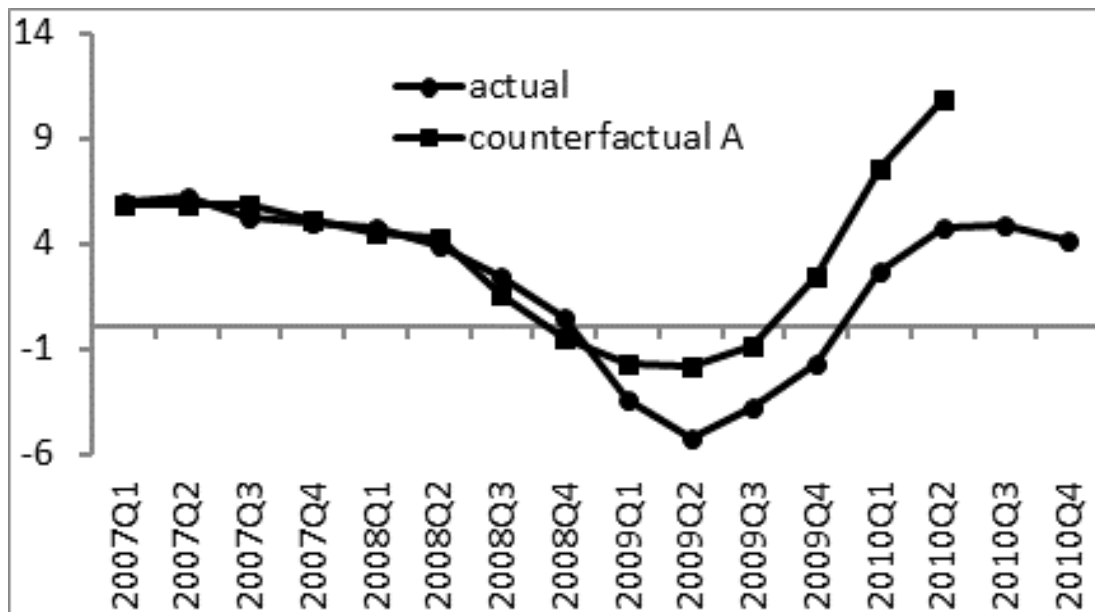


Figure 3.9: Nominal GDP growth under counterfactual A



3.4.4. The effect on nominal income of QE

I now turn to assess the impact of quantitative easing on nominal GDP growth, given the occurrence of the financial crisis, by constructing a counterfactual path for monetary growth. Given the complexity of the issue and the various offsets to QE which have been identified by Bridges et al. (2011), I construct three different counterfactuals (see also Table 3.5 above). First, if there were no offsets to QE at all, then M4ex in the absence of QE would have been lower by the cumulative amount of the asset purchases: in this counterfactual B money growth falls much faster than the historical series, turning negative in 2009 Q2, reaching -11.6% in 2009 Q3 but then returning towards the historical series as QE begins to fall out of the four quarter interval during 2010.

Second, there is an important offset highlighted by Bridges et al. (2011): the effect of ‘banking sector stabilisation’ in the form of (a) banks’ issuance of new equity and bonds which raises their non-deposit liabilities and reduces their deposits (see row 2 in Table 3.3), and (b) banks’ acquisition of additional public sector debt in order to improve their liquidity ratios, which increases their deposits (see row 3 of Table 3.3). It is likely that some banking sector stabilisation of these kinds would have occurred in the absence of QE, since banks needed to improve their capital ratios after the revelation of large housing-related bad debts. But it could be argued that the stabilisation was facilitated by QE: QE meant that ‘other financial corporations’ (OFCs), notably pension funds and life assurance companies, which had sold their gilts to the BoE now had extra resources to invest, and this may have encouraged banks to issue new paper. I therefore construct a counterfactual C under which nominal money was lower by the amount of the ‘excess’ lending by MFIs to the public sector (which includes both QE and commercial banks’ purchases of gilts), net of the ‘excess’ increase in MFIs’ non-deposit liabilities, where the excess is the deviation from the respective averages for 1997 Q4 to 2007 Q4.

Third, Bridges et al. (2011) have also raised the issue of private non-financial corporate issuance. Here the argument is that PNFCs may have been issuing more equity and bonds over the QE period because OFCs were willing to buy, as with bank issuance, but

this might reduce the PNFCs' demand for credit and hence their borrowing from banks, in which case the stock of M4ex lending and M4ex itself would be lower by the (cumulative) amount of PNFC issuance. I therefore construct a final counterfactual D by adding to the nominal M4ex implied by counterfactual C the amount of PNFC issuance from 2009 Q2 in excess of the average issuance from 2003 Q1 to 2008 Q4 (the period for which the data are available on the Bank's website).

The paths of nominal money growth under these counterfactuals are shown in Figure 3.10. Counterfactual B implies the largest effect from QE, counterfactual C a smaller effect and counterfactual D an even smaller effect. As stated above there is evidence that the fall in bank lending was more of a supply-side phenomenon. To the extent that the fall was supply-driven then additional PNFC issuance would be providing firms with additional resources without reducing the amount of firms' borrowings from the banks, so the size of the offset would be smaller. It is also arguable that much of the banking sector stabilisation would have taken place, necessarily, even in the absence of QE. So while counterfactual D can be regarded as the lower bound (and it is close to the lower bound suggested by Bridges et al., 2011), it seems likely that the 'true' counterfactual would involve a somewhat larger fall in nominal money growth, somewhere between counterfactuals B and D. It should also be noted that there is a sharp jump in nominal money in 2010 Q1 under counterfactuals C and D. This is the result of an exceptionally large rise in banks' non-deposit liabilities in that quarter, followed by a fall in 2010 Q2, and of the fact that the assumptions defining the counterfactuals are taken to hold beyond the end of QE (in January 2010). This means that for these two counterfactuals more weight should probably be attached to the results for 2009 than for the later quarters.

Figure 3.10: Money growth under counterfactuals B, C and D

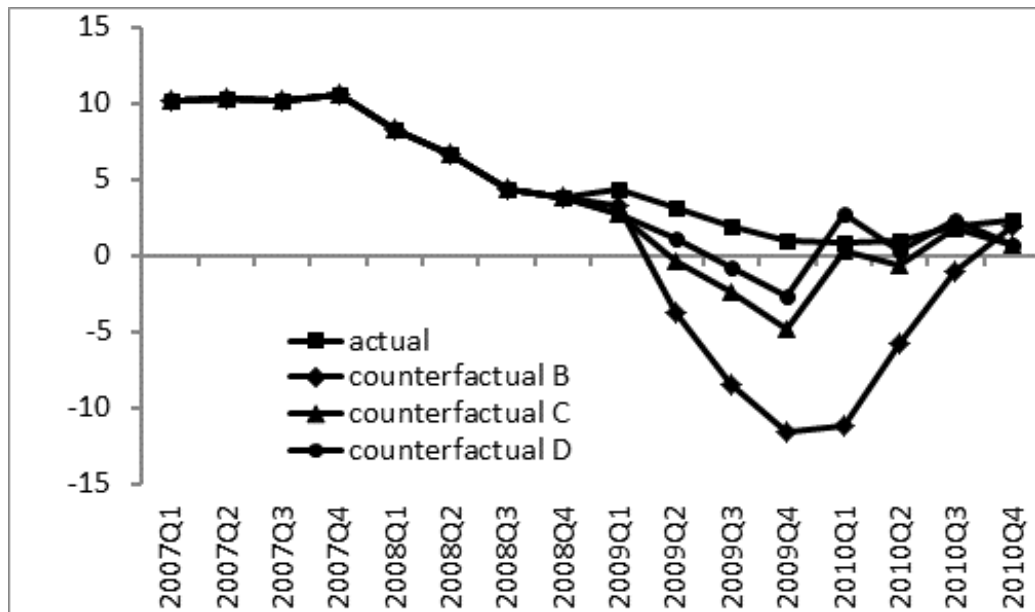
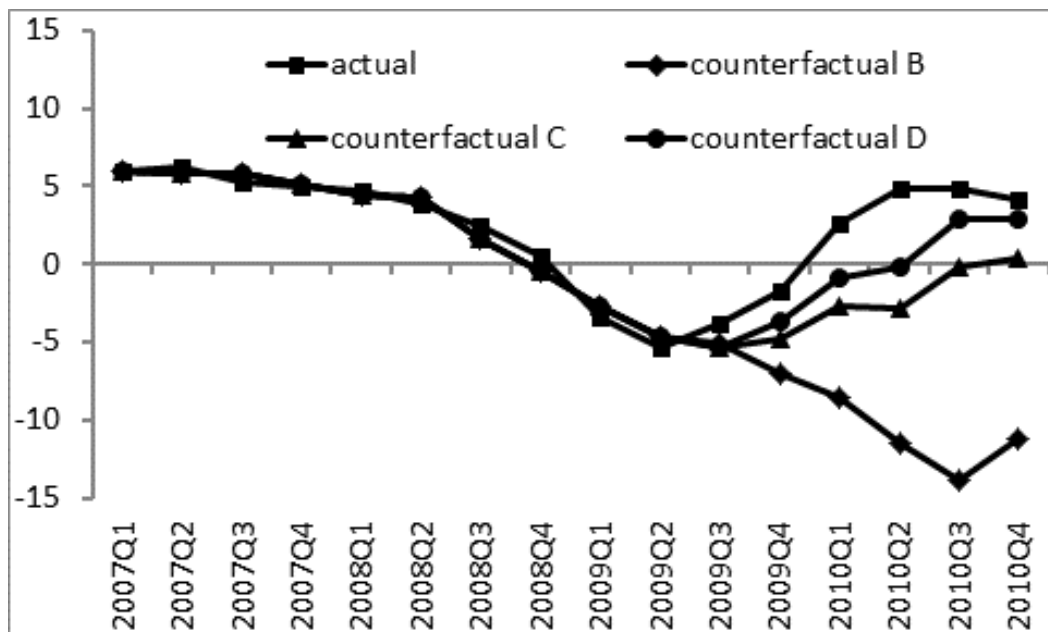


Figure 3.11: Nominal GDP growth under counterfactuals B, C and D



These counterfactuals are then used to find what the nominal GDP growth rate would have been in the absence of QE, as understood in each case. Figure 3.11 shows the actual path and those predicted under counterfactuals B, C and D. In each case the difference between the actual and the counterfactual paths of nominal GDP can be interpreted as a (rough and suggestive) estimate of the effect of QE under the relevant assumptions. On counterfactual B, that is if no QE was undertaken and there were no offsets to it, growth falls heavily to a trough of -13.8% in 2010 Q3, before turning up. On counterfactuals C and D, where there are assumed to be varying offsets, growth improves from 2009 Q3 but becomes positive only in 2010 Q3 and 2010 Q4 respectively, whereas actual (and predicted) nominal spending growth rose above zero in 2010 Q1. The implication is that in the absence of QE nominal spending growth would have been considerably weaker for longer. In other words QE did indeed have a significant impact on nominal spending and hence economic activity in the UK.

There are two papers I mentioned in section 3.2 which used structural VAR models to estimate the macro impact of QE. Bridges and Thomas (2012) has an estimate of the impact on the level of GDP of 2% and on CPI of 1%; Kapetanios et al (2012) estimated the impact on GDP at 1.5% and that on CPI at 1.25%. My 'pure-QE-shock' estimation for year 2010 under the SVAR of the impact on GDP is 2.5% and that on CPI is 0.4%. An article in the Bank's *Quarterly Bulletin* (Joyce et al. 2011) has also reported a number of estimates of the peak effect of QE on real GDP and CPI inflation taken from ongoing research at the Bank: the range for GDP is 1.5-2%, and that for CPI inflation is 0.75-1.5%. If I take the sum of these to be a reasonable estimate of the change in nominal GDP, this comes to around 2.25% to 3.5%. In Figure 3.11, the difference in the four quarter nominal GDP growth rates as of 2010 Q1 (the QE period) between the predicted rate and the rate on counterfactual D (which implies the smallest impact of QE) is also of the order of 3%, while the differences with counterfactuals C and B are around 4.8% and 10.6%. On the other hand, my corresponding estimates of the peak effects are 4.6% and 7.2% for the four quarters to 2010 Q2 on counterfactuals D and C, and 18.2% for 2010 Q3 on counterfactual B. Thus my estimates for the effect of QE are typically a

little higher than those reported by the Bank, particularly if the ‘true’ counterfactual is agreed to be somewhere between B and D, as argued above.

How might QE influence the economy? The counterfactuals indicate how much the money might have influenced nominal spending and now I would like to explain how this may have occurred. Benford et al (2009) suggested several transmission channels for QE. Joyce et al. (2011) also list several possible transmission channels of QE. Those channels are the expectation channel, the asset market channel (includes portfolio rebalancing and signaling) and the bank lending channel. When financial companies hold more money because they have sold their gilts to the central bank, they would be expected to purchase other assets to rebalance their portfolios. This could push asset prices up and lower yields. The increased willingness to hold illiquid assets in the market would make investors more confident in selling their assets and thus further lower the yields. So in the asset market, the increase in total wealth and the decrease in borrowing cost together lead to higher nominal spending. On the other hand, banks gain more money through QE and they would like to hold more illiquid assets in the form of loans. The private sector has easier access to loans, which encourages consumption and investment. Even if banks do not lend more, they could also switch some liquid money to other assets, which would lower the interest rate. Finally, QE could make people believe that the interest rate would be kept at a low level and the inflation is really anchored to the inflation target, which should encourage both current spending and investment. Unlike the papers which study the yields on various assets and emphasize the portfolio rebalancing channel, my analysis on the effect of changes in money encompasses all those transmission channels. David Miles in his speech also supported the idea that the effect of money in QE covered all transmission channels. : *"the effects are a bit like those from pumping water into a dry area: it is hard to know which channels the water will flow down, and much of it will seem to disappear, but that does not mean we are clueless on the nature of its impact...One can be unsure which are the most important channels, but most of them are helpful and it seems to me that none, in the current environment, are obviously harmful."*

3.5. Conclusions

Formal announcements of the introduction of quantitative easing emphasized the intended impact on money and credit and hence on nominal spending, but the main empirical research focuses on the effects of QE on long-term interest rates rather than money or credit. In this Chapter I have tried to see whether there is a direct connection between nominal spending growth and monetary growth, which I argue is very likely to have been significantly affected by the financial crisis and quantitative easing. The approach can be thought of as covering the range of possible transmission mechanisms, and connecting money with the object of ultimate interest, nominal spending, rather than say long-term interest rates. The results obtained should be treated as tentative, since they have been derived using a simple ad hoc reduced form equation rather than a more comprehensive model, and since it is only possible to give a range of counterfactuals on different assumptions. Nevertheless, they suggest strongly that changes in money have had a considerable impact on the economy in the last few years, and a much greater impact than in the pre-crisis period. This is consistent with the idea that in tranquil time money may not embody significant additional information, but that in other periods changes in banks' behaviour may affect money, credit, nominal spending and the real economy. Moreover, they imply that QE has indeed had a major impact on the UK economy, and a somewhat larger impact on this analysis than that reported by the Bank of England.

For this period at least broad money would indeed appear to tell us something, enough to suggest that more research would be appropriate. It may not be possible to gain further insights by working on simple reduced form models. Instead, these results are strong enough to suggest that operators of large macroeconomic models of the UK economy, notably the Bank of England, should experiment with the inclusion of monetary and credit variables in their models. The Bank's (published) monitoring of money and credit could also be deepened.⁴⁸

⁴⁸ It is notable that ECB's *Monthly Bulletin*, contains a more substantial analysis of money and credit than the BoE's *Inflation Report*, while the BoE also has no parallel to the large-scale macroeconomic model of Giannone et al. (2009), which provides the basis for their (2011) estimates of the effect of the ECB's non-standard policy measures.

Chapter 4. Inflation, Crisis and Money

4.1. Introduction

Since inflation targeting was introduced in the early 1990s, the Bank of England (BoE) had successfully kept inflation around a desirable level for nearly twenty years by adjusting Bank Rate. Studies on the monetary policy of the BOE in this period concerned the issues of the interest rate response to the economy. Especially since Taylor-Rule type reaction functions had been used as a good description of what the central bank had done, most recent research suggested that there was no big question in monetary policy which could not be addressed by changing the interest rate. To be more precise, the New-Keynesian Model which consists of three equations was considered good enough to explain the economy and other macro variables which were not included in this model were often ignored. However, since the financial crisis broke out, most central banks have decreased their interest rates close to the zero bound, and could not decrease them further. Under such a situation, when the interest rate is not flexible enough to react to the inflation and output problems in the economy, how far could we go if we still depend on the old theory without extra attention to other variables?

The BoE adopted Quantitative Easing (QE) at the beginning of 2009 with the announcement of “*the aim of boosting the supply of money and credit*”.⁴⁹ This suggests that it is the time to pay some attention to monetary aggregates. Though the aggregate money has been shown in the *Inflation Report* since it started twenty years ago, this does not prove that money had a strong role in the monetary policy of the BoE. Moreover, it seems that there was not a clear agreement even among the MPC members that money contains useful information when they made decisions. In Chapter 3, I focus on the impact of money growth on output and I found that the change in money did have an influence on nominal spending in the medium term. However, the BoE is a formal inflation targeting central bank, stabilizing inflation well is their first objective.

⁴⁹ See the press statement of 5 March 2009, at <http://www.bankofengland.co.uk/publications/news/2009/019.html>, and the minutes of the MPC meeting at <http://www.bankofengland.co.uk/publications/minutes/mpc/pdf/2009/mpc0903.pdf>.

The attention to GDP growth is an important way to help targeting inflation in the short run but not the only way. Besides the indirect short term effect of money on inflation through nominal spending, it is worth investigating the link between money and inflation directly. This chapter emphasizes the study of inflation decomposition and the link between money and inflation. As the link between money and inflation was hardly detected directly by some past research, several authors have recently suggested estimating inflation in a reduced-form “Phillips Curve” equation.⁵⁰ In this equation, money is used as an important component when looking at inflation from a long-run perspective. This is in accordance with the research on the Quantity Theory which was widely undertaken in the 1960s to study money and inflation. Besides quantity-theoretic variables, some real economic variables are included to show their link with inflation in the short run. The idea of explaining inflation from two perspectives in one equation makes it easy to see not only what variables should be linked with inflation but also at what frequency they show the links. This advantage prevents people from ignoring factors that work in other time horizons.

Furthermore, as money is being given attention by policy makers now that unconventional policy has been adopted, the estimation in this paper is done on two periods. One is the estimation of ‘normal time’ which stops before 2008 and the other is until the end of 2010. The purpose of doing so is not to show that money works in crisis periods but not in tranquil periods. Instead, the comparison is to support the idea that money is always useful in looking at inflation and it has a certain link with inflation in the long run.

The rest of the chapter is organized as follows. Section 4.2 is a literature review. The first part goes through the history of monetary theory. The second part focuses more on some recent research conclusions on different types of study of long-run relationships between inflation and other variables. Section 4.3 sets out the methodology. The technique used in this paper is based on frequency-domain technique, which is quite similar to the method of Assenmacher-Wesche and Gerlach (henceforth AWG)

⁵⁰ See Gerlach(2003) and Assenmacher-Wesche,K., and S.Gerlach (2006b).

(2006b)⁵¹. In section 4.4, after the estimation of the inflation equation, I do two further estimations which are at low frequencies and high frequencies respectively. All the estimations are done both for before the crisis and after the crisis. In order to show the relationship between money and inflation, output gap and inflation, I do a measure of causality. Section 4.5 is the conclusion.

4.2. Literature Review

4.2.1. *The history of the study of money*

The study of money goes back over many centuries. In particular, the classical quantity theory, as proposed in the 18th century or even earlier, argued that there is a long-term relationship between price and money. At that time, the classical quantity theory did not raise the notions of “money demand” or “money supply”. Instead, the theory only gives a general equation to show the relation between money and inflation. The version of the quantity theory we usually study today is $MV=PY$ where M is the quantity of money, V is the velocity, P is the price level and Y is the real output. The right hand side of the equation is nominal income in the economy while the left hand side is the money in circulation times the velocity. Later writers introduced other variables into this relationship, notably the interest rate. However, such developments modified and maintained, rather than eliminated, the long term relation between money and inflation.

Fisher (1911) defined what is referred to as the classical quantity theory. In this version, money is identified as a means of transaction only and the equation is written as $MV=PT$ where T is the volume of transactions. The explanation of this function is that M , V and T are taken as exogenous variables and thus the price level P is determined by M . The exogenous velocity V is assumed to depend on the ‘institutional arrangements’ in place in the time and country concerned, which are assumed not to vary much in the short run. Thus under the assumption of constant V and T , P must fluctuate with M , proportionally.

⁵¹ AWG is short for Assenmacher-Wesche, K., and S. Gerlach. The paper ‘AWG (2006b)’ refers to ‘Understanding the link between money growth and inflation in the euro area’.

The classical quantity theory was then developed by the Cambridge school, the main representative of which is Pigou. In contrast to the classical school, the Cambridge school brought the money demand question into the field of individual choice, making it more specific than the general description of classical theory. In the individual-level analysis, money is held for convenience and there is an opportunity cost to holding money. Though the Cambridge school did not explicitly consider the interest rate in their theory, they did mention other variables which could influence money holdings such as holding costs. Besides, they also put income Y rather than transaction volume T into the equation. Thus the overall national money demand was a function of national income.

Though the Cambridge school had developed the quantity theory in which money is related to price, national income and holding costs, it still took money to be demanded for transaction purposes only. Keynes used the Cambridge approach to develop the quantity theory further. In Keynesian theory, money is held for transactions and precautionary motives, which indicate the role of national income in the equation, but also for the speculative motive. The speculative motive introduces the interest rate into money demand and treats it as a key reason for agents to hold bonds or money. Keynesian theory suggested that for every person, there was a range of interest rates which were considered as normal values. If the current interest rate level is above the “normal level”, the interest rate would be expected to fall. Since bond prices vary inversely with interest rates, the expectation of an interest rate fall encourages individuals to hold bonds instead of money. Conversely, a relatively ‘low’ interest rate would push some people to switch from bonds into money, and would therefore lead to a rise in money demand. So Keynesian theory suggests that the interest rate has a negative effect on money demand. And because the range of the ‘normal’ interest rate would vary across time it also suggests that the relation between the interest rate and money demand is unstable.

Though Keynesian theory introduced the interest rate into monetary theory as the cost of holding money, the role of money was still that of means-of-exchange only. If money

is treated as a special kind of asset, the demand function would be more complicated. In Tobin's (1958) model, money is taken as a riskless but zero-return asset. Risk-averse individuals with fixed wealth (a budget constraint) would balance the weights of it and those risky but interest rate earning assets (bonds, equity etc.) to reach their maximum utilities. The relationship between interest rate and money in this model, in contrast to what Keynesian theory suggested, however, is not negative all the time. When the interest rate rises, under the substitution effect bond holding increases and thus money demand decreases. However, the wealth effect of an interest rate change could either reinforce the substitution effect or go in the opposite direction. The combination of these two effects would lead to an increase, a decrease or no change in money holding. Thus in the Tobin model, we can only be sure that the interest rate could change money holdings but we cannot figure out the direction.

Keynes's theory of money, developed from the Cambridge approach, starts from the personal motives for holding money. The classical theory, on the other hand, focuses on the general theory of money. This is further emphasized by Friedman (1956) again and formed "modern quantity theory". In Friedman's theory, money demand is a function of wealth, interest rates, level of price and the rate of price change. What is particularly characteristic of money demand here is that, besides the price level, Friedman thought the price change could be taken as an own return of money which is not only related to nominal money, but to real money as well. When other variables are stable, the higher the rate of price change is, the less the money demand is. But for the price level, it is the reverse. The higher the price is, the more the money demand is. So in Friedman's theory, the role of inflation is implicitly emphasized in the equation.

To sum up the development of monetary theory by different schools, we could make a more sophisticated quantity theory of money which indicates that money is related to price, output and interest rate.⁵² The relation between money and output is positive; the price has a proportional relationship with money; and for the interest rate, it is more

⁵² For more studies on monetary theory, see Laidler, D.E.W (1985) *The demand for money, theories evidence and problems*.

widely accepted that the substitution effect of an interest rate change dominates the direction of money holding. Thus the interest rate has an inverse relationship with money. This chapter is concerned mostly with the relationship between money and inflation.

4.2.2. Some empirical work on the relationship between money and inflation

Though theories can explain the events in the economy by mimicking human motives and logical reasoning, empirical evidence is needed. Since the 1950s, many researchers have tried to empirically estimate those relationships. Lucas (1980) illustrated empirically two implications of QTM: one is that money growth rate would lead to an equal change in the rate of inflation; and the other is that money change induces an equal change in the interest rate. Lucas plotted the quarterly data of US during 1955—1975. He found that the figures for the original CPI and M1 growth rate did not show a one-to-one relationship. Nor did the figures of interest rate and M1 growth rate. However, when he started to use moving-average data, the linear relationship began to show up. He found that when very low-frequency components were extracted from the data, the one-to-one relationship between inflation and money growth became clear, and similarly that between interest rate change and money growth. This result suggested that the proportional relation in inflation and money was a matter of “long-run average behaviour”. Besides Lucas, Vogel (1974) studied 16 Latin American countries between 1950 and 1969 and he also showed a proportionate change in inflation after the change in money growth within two years. De Grauwe & Polan (2005) used data for 160 countries over 30 years and tried to find out whether inflation and money have a proportional relationship. When they used the full sample to do cross-section estimation, they found that the result suggested a greater-than-one coefficient of money on inflation. However, as the authors divided the data into high-inflation episodes and low-inflation episodes, the linear relationship between inflation and money growth became weak in the low-inflation episodes. And the larger-than-one relationship still existed in high-inflation episodes. The authors further checked this relationship by using panel data in their high-inflation group. They concluded from the evidence that due to velocity

change in high-inflation episodes, inflation could exceed the percentage increase in money growth and the time the transmission takes is approximately one year. Chrystal and Mizen (2011) revisited some work on money and its relations with other variables. The results of their regressions on inflation are quite similar when they used two definitions of money: retail M4 and M4ex (M4 excluding intermediate OFCs) in the UK. They found clear evidence of cointegration relationships between the quantity theoretic variables and in particular their estimation showed a long-run relationship between money and inflation. The coefficient of money was 1 while the coefficient of GDP was -1, which was in line with the money demand equation. And their causality test showed two-way causation between money and inflation.

There are some similar conclusions from the results of the papers. Most people agreed that there is a relationship between money and inflation in the long run, direct or indirect. And the interest rate also has a role in the equation of the quantity theory. However there are some disagreements as well. Some evidence shows a proportional relation between money and inflation while other evidence does not. I believe that when we use the data for different countries over different periods to do a relatively long-run estimation, we can hardly get the same result due to the specific characteristics of country technology or special time horizons. What's more, the methods people have used to estimate a 'long-run' relationship have varied. As De Grauwe & Polan (2005) mentioned, some researchers have used cross-section data on some countries over a long time span; and some have used annual or quarterly data for one specific country over a long time span to estimate the relationships. For the first type, Nelson (2003) pointed out the flaws. He considered that the non-inflationary monetary growth rates were not identical across countries and thus using cross-section data would impose a common trend on velocity across countries.

When one focuses on one-country analysis, he would use a long data series to estimate. There are three ways to define 'long-run' in regression. One is to include lagged values. Studies of this type have mostly constructed VAR or SVAR models to find evidence. Nelson (2010) suggested that "recovering the relation between money and inflation

involves looking at the relation between inflation and prior money growth”. According to his correlation tests, money growth leads inflation by one quarter. Including the lagged monetary values as explanatory variables helps explain the inflation on the left hand side.

The second way to include past information on money is to use the average value of the variables. Lucas (1986) suggested using long moving averages to take out the long-run relation between money and inflation. His work (1980 and 1986) used this method to get a significant and close to one coefficient of money on inflation. Fitzgerald (1999) also estimated the relation between money and inflation on average values. He took 2-year averages, 4-year averages, and 8-year averages of the annual growth rate of money and inflation from 1959 to 1999. He found the relationship became closer for longer time averages and the variation in money accounted for more of the variation in inflation.

The third way of looking at the long-run relationship is to use a filter to get ‘core’ inflation and ‘core’ money growth. The idea of this methodology is to extract the long-run component of the variables and then study the relation among them. Neumann (2003) investigated the role of money in explaining inflation of the Euro Area during 1980 to 2002. He applied the HP filter to get the long-run components, which he preferred as a two-sided filter that is not solely depending on past information and is widely used for inflation expectations. The result of his paper suggested that the core inflation of the Euro Area during this period was driven by permanent money growth. The M3 growth rate was the dominant factor explaining the inflation of the Euro Area before and after EMU. Cogley (2002) proposed a new measure of the core components—the exponential filter. According to this paper, this filter would be an ideal filter if a suitable coefficient was chosen. And as a one-sided filter it can be implemented into real time, which is more useful to monetary policy makers, relative to the two-sided filter (See Cogley, 2002, p102). Gerlach (2004) used Cogley’s filter to investigate the relation between money and inflation for the Euro area. His results suggested that the long-run component of money was important during the 1970s and 1980s when inflation at that

time was high. There is another paper which uses four methods to study the money-inflation relationship, which is Neumann and Greiber (2004). In this paper, the authors applied the HP filter, exponential filter, BK filter and wavelet analysis respectively to money in the Euro area and tried to corroborate the results. They suggested that there was a stable relation between the core components of money and inflation over four measures and the one-to-one relationship was also supported by the result.

Besides the time-domain analysis, the inflation-money relationship has also been studied using frequency-domain techniques. Jaeger (2003) studied the two-pillars strategy of the ECB using spectral analysis. One of his findings is the co-movement of money and inflation at low frequencies. Bruggeman, Camba-Mendez, Fischer and Sousa (2005) developed structural filters based on spectral analysis. By applying double-sided and one-sided filters respectively, they found the correlation between money and inflation in the long run is strong while the output gap becomes significant in explaining inflation in the shorter term.

Besides the papers above, the idea of this chapter comes more from the work done by Karin Assenmacher-Wesche and Stefan Gerlach (2006). In their paper “Understanding the link between money growth and inflation in the Euro Area” (AWG, 2006b), they used frequency-domain technology to assess the two pillars strategy of the ECB, offering evidence on “the determinants of inflation at different time horizons”. (See p.12) When the ECB reviewed its monetary strategy in 2003, some research pointed out in the *Monthly Bulletin* (2003 June, p.87) that “*the inflation process can be broadly decomposed into two components, one associated with the interplay between demand and supply factors at high frequency, and the other connected to more drawn-out and persistent trends. The latter is empirically closely associated with the medium-term trend growth of money*”. AWG (2006b) took variables in the quantity-theory, including money, as “persistent trends” and used the output gap as well as several cost-push variables as factors at high frequency. In their band spectral analysis, the authors took four years as the dividing line between high-frequency behavior and low-frequency behavior. They first ran the regression at low frequencies and the results showed that the

quantity-theoretic variables were significant while the output gap was not, as expected. But the unexpected thing was the significance of cost-push variables when they were included in the regression separately. Then the authors moved to regressions at high frequencies. The results they got showed the insignificance of quantity-theoretic variables but the significance of the output gap as well as the significance of the cost-push variables when the high frequencies consist of the period between 0.5 to 4 years. If they tightened the high frequencies to 0.5-1.5 years, the cost-push variables remained significant and the output gap was not. Thus the authors ran regressions of inflation based on two-pillar Phillips Curve to do their analysis. The right-hand-side variables were decomposed into different frequencies, which were the low-frequency component of the quantity-theoretic variables, the high-frequency behavior of the output gap and the even higher-frequency part of cost-push variables. The evidence suggested that the quantity-theoretic variables, especially the money growth, were important in determining inflation at low frequencies while the output gap was much more important at high frequencies and the cost-push variables were significant at even higher frequencies.

4. 3. Methodology

As I have mentioned in the last section, the methodology I use to investigate the determination of inflation in this chapter involves frequency-domain techniques, the motivation for which comes from AWG (2006b). A time series like inflation, from the frequency-domain perspective, consists of different periodic components. As the ECB claimed in its *Monthly Bulletin*, “*The inflation process can be broadly decomposed into two components, one associated with the interplay between demand and supply factors at high frequency, and the other connected to more drawn out and persistent trends.*” (See ECB *Monthly Bulletin*, June 2003, p.87) Not only the inflation in the Euro Area, but other time-series can be decomposed into high frequencies and low frequencies. Low-frequency movements in series could be taken as long-run terms while high-frequencies reflect short-run variations. If we try to study the relations in those variables at a specific periodicity, it is natural to extract the corresponding

frequency components and then run spectral regressions on them.

In AWG (2006a), the authors tried to explore “*the hypothesis that the two pillars, the monetary and economic analysis, contain information useful for understanding inflation in the euro area at different time horizons using frequency domain methods.*” (p.3) A reduced-form Phillips-Curve equation is estimated to “*understand the inflation...at different time horizons*”. Their procedure is firstly to take the Fourier Transform of the series associating different frequencies into the frequency domain. Then they extract the required frequency band and filter out the other frequencies. Thirdly they transform these ‘required frequencies’ in the frequency domain back to the corresponding components in the time domain. Finally the inflation equation is estimated by using those filtered series and the estimated coefficients are viewed as evidence of relations at certain frequency bands. Baxter and King (1999) viewed this band-pass filtering process is “*a common approach*”. (p.580) Hassler, J., P.Lundvik, et al. (1992) also used this frequency-domain method to study relations at different frequency bands.

When AWG (2006b) tried to find out the long-term relationships between quantity-theoretic variables, particularly the relation between money and inflation, they followed the band-spectrum regression in Engle (1974). Engle argued that one model may not fit all frequencies. “*It may be useful to specify that a model applies for some but not all frequencies*”. (See p.4) By applying a Fourier transform to the time-domain variables, they transformed the series into the frequency-domain, whose observations are in different frequencies, from low to high. In the transformed regression, Engle chose some frequencies and added the selected frequencies that are needed together to do the estimation. Finally, Engle proved that the estimator could be written as:

$$\hat{\beta} = \left[\sum \widehat{f}_x(\theta_k) \right]^{-1} \sum \widehat{f}_{xy}(\theta_k)$$

where Σ is defined as the sum over the included frequencies; $\widehat{f}_x(\theta_k)$ is defined as the periodogram of x; $\widehat{f}_{xy}(\theta_k)$ is the cross periodogram between x and y; T is the number of observations while $k=0,1,\dots,T-1$.

In Engle's method, the assumption of stationary, zero-mean variables is required. AWG (2006b) did unit root tests for all variables and found that all variables were stationary except inflation and money growth which were $I(1)$. Thus they did a co-integration test between money and inflation. The results suggested that there was a co-integration relation between the two variables. In order to use Engle's method, the authors put a unit restriction on money growth and used the difference between inflation and money growth which is stationary as the dependent variable and put the other quantity-theoretic variables including the interest rate change and GDP growth rate on the right side of the equation. In other words, AWG (2006b) chose a method to 'produce' stationary variables as required for band spectral regression before transforming them into frequency-domain variables.

As Engle's estimator only works on stationary variables, an alternative way of estimating the relation between money and inflation is to use Phillips's (1991) estimator which is suitable for $I(1)$ variables which have cointegration relationships. This method is used and discussed in detail in AWG (2006a)⁵³. As there is no cointegration between money and inflation in the UK, Phillips's estimator is not discussed in my work.

In this paper, the estimates will not be precise if I follow the methods in AWG (2006b) completely because the characteristics of the data in UK are quite different from the data in the euro area. The biggest difference lies in whether inflation, quarterly money growth and output gap are stationary or not. Table 4.1 and Table 4.2 show the unit-root tests on the series for periods from 1975 to 2007 and from 1975 to 2010 respectively. In both tables, with 95% significance we can reject the null hypothesis of inflation having a unit root after including an intercept and a trend under both the ADF test and the PP test. The same is true for money growth. This suggests that money growth and inflation have only deterministic trends but not stochastic trends under both tests. For the output gap, however, it is also hard to judge whether it is $I(1)$ or not. For the output gap between 1975 and 2007, two tests indicate it is a stationary variable while for this series

⁵³ This paper is 'Interpreting euro area inflation at high and low frequencies'. The details of the Phillips estimator can be found in Phillips (1991) and it will not be applied in this paper for the reasons discussed later.

over 1975 to 2010, two tests suggest it is I(1). Other variables are stationary without trend and their means are insignificantly different from zero.

Estimating the Phillips-Curve equation in AWG (2006b) is the first and the main task I am going to do in my work, which will suggest the determination of inflation in the long term and short term. Before I start the “common approach”, Baxter and King (1999) suggested that predetrending the series in the time domain before taking the Fourier Transform is necessary, as stationary variables are required. (See p.580) In the UK data, there are deterministic trends in inflation and money growth, and a stochastic trend in the output gap. However, directly removing those trends in the time domain before using the Fourier Transform may distort the estimation that follows, as suggested by Corbae and Ouliaris (2002).

Table 4.1: Unit-Root Test (1975 to 2007)

Variables	ADF test	PP test	KPSS test (null: stationary)
Inflation(incl. trend)	-3.28*	-9.45***	0.20**
Money growth (incl. trend)	-7.02***	-7.34***	0.12*
GDP growth	-4.03***	-11.69***	0.17
Interest rate change	-10.04***	-10.03***	0.05
Output gap	-3.08**	-2.50	0.05
Exchange rate change	-9.78***	-9.69***	0.06
Import price change	-6.96***	-6.88***	0.93***

Table 4.2: Unit-Root tests (1975 to 2010)

Variables	ADF test	PP test	KPSS test(null: stationary)
Inflation(incl. trend)	-3.67**	-9.53***	0.23***
Money growth (incl. trend)	-7.23***	-7.54***	0.09
GDP growth	-5.40***	-9.97***	0.11
Interest rate change	-10.32***	-10.31***	0.08
Output gap	-0.47	-0.10	0.30
Exchange rate change	-9.91***	-9.91***	0.05
Import price change	-7.33***	-7.25***	0.72**

In Corbae and Ouliaris (2002), the authors showed how biased and inconsistent estimates are introduced when we simply remove the deterministic trend and stochastic trend at the very beginning. When both dependent y and independent variables x contain deterministic trends, they would be written as:

$$\begin{aligned} y_t &= z_t \pi_1 + \tilde{y}_t \\ x_t &= z_t \pi_2 + \tilde{x}_t, \end{aligned} \quad (4.1)$$

Where $z_t=(1,t,\dots,t^p)$ is the deterministic trend, \tilde{y}_t and \tilde{x}_t are stationary/non-stationary data with zero mean.

Let $\tilde{X} = [\tilde{x}_1, \tilde{x}_2, \dots, \tilde{x}_n]'$ be the matrix of observations of the regressor \tilde{x}_t , $\tilde{y} = [\tilde{y}_1, \tilde{y}_2, \dots, \tilde{y}_n]$. Detrending the data at the beginning can be expressed as $Q_z X$ and $Q_z y$. Let the Fourier Transform matrix $W = (w_0, w_1, w_2, \dots, w_{T-1})'$ where $w_k = (1, e^{i\theta_k}, e^{2i\theta_k}, \dots, e^{(T-1)i\theta_k})$ and $\theta_k = 2\pi k/T$. W^* is the complex conjugate transpose of W . Define A as the selector matrix that only keeps the relative frequency band B_A and thus A^C represents the residual frequencies over B_A^C . Thus $A^C * A = 0$ and AW extracts frequency band B_A . Let $\psi = W^* AW$ and $\psi^C = W^* A^C W$. β_A and β_{AC} are coefficients over B_A and that over the left band B_A^C respectively. (See Corbae and Ouliaris, 2002, pp.1075-76)

If we removed the trends at the beginning, \tilde{y} is generated by the system

$$AW\tilde{y} = AW\tilde{X}\beta_A + AW\varepsilon, \quad (4.2)$$

$$A^C W\tilde{y} = A^C W\tilde{X}\beta_{AC} + A^C W\varepsilon, \quad (4.3)$$

Adding (4.2) and (4.3), and multiplying by W^* gives

$$\tilde{y} = \psi \tilde{X}\beta_A + \psi^C \tilde{X}\beta_{AC} + \varepsilon, \quad (4.4)$$

Put (4.4) into (4.1),

$$y = z(\pi_1 - \pi_2\beta_A) + X\beta_A + \psi^C z\pi_2(\beta_A - \beta_{AC}) - \psi^C X(\beta_A - \beta_{AC}) + \varepsilon \quad (4.5)$$

In equation (4.5), regressor x is band dependent coefficient β_A and β_{AC} . So is the trend z . So Corbae and Ouliaris (2002) argued that trend removal is not simply putting Q_z on the series as the trend is also band-variant. They further illustrate how the estimator of the coefficient could be biased. The estimator for the required band B_A has the form:

$$\widehat{\beta}_A = \beta_A - \{X'Q_z \psi Q_z X\}^{-1} \{X'Q_z \psi Q_z y\} \quad (4.6)$$

Using (4.5) and (4.6), the estimator will be

$$\widehat{\beta}_A = \beta_A - \{\tilde{X}'Q_z \psi Q_z \tilde{X}\}^{-1} \{\tilde{X}'Q_z \varphi Q_z [\psi^C \tilde{X}(\beta_A - \beta_{AC}) - \varepsilon]\} \quad (4.7)$$

And the expected value can be shown to be:

$$E(\widehat{\beta}_A|X) = \beta_A - \{X'Q_z \psi Q_z X\}^{-1} \{X'Q_z \varphi Q_z \psi^C \tilde{X}(\beta_A - \beta_{AC})\} \quad (4.8)$$

From (4.8), we can tell that the estimates of the coefficient is biased when $\beta_A \neq \beta_{AC}$ if the trend is conventionally removed. However, the authors also said that this bias would disappear as n goes to infinity if \tilde{X} and \tilde{y} are stationary.

To overcome the drawback of conventional trend removal, Corbae and Ouliaris (2002) suggested taking the Fourier Transform of the series including the trend and then removing the undesired frequency band. So it is not the total trend that is deleted but the trend at B_A^C which is removed. In the frequency domain, this procedure can be explained as detrending in the performance of the regression, which is:

$$\widehat{\beta}_A^f = \beta_A + \{X'W^*AQ_{awz}AWX\}^{-1} \{X'W^*AQ_{awz}AW\varepsilon\} \quad (4.9)$$

Clearly the estimator is unbiased. (Corbae and Ouliaris, 2002, pp.1080)

For I(1) variables which contain a stochastic trend, Corbae and Ouliaris (2002) showed that their Fourier transforms are frequency-wise dependent and the leakage exists even if the sample size goes to unlimited. Their LEMMA B in that paper shows this problem:

$$w_{\tilde{x}}(\theta_k) = \frac{1}{1-e^{i\theta_k}} w_v(\theta_k) - \frac{e^{i\theta_k}}{1-e^{i\theta_k}} * \frac{(\tilde{x}_n - \tilde{x}_0)}{\sqrt{n}} \quad (4.10)$$

where \tilde{x} now is an I(1) variable and v is its first difference which is stationary. $w_{\tilde{x}}(\theta_k)$ represents the Fourier transform of \tilde{x} at frequency θ_k .

LEMMA C in Corbae and Ouliaris (2002) shows this leakage is strong and will not disappear even though the data have been first detrended in the time domain. However, another paper by the authors gives a frequency domain filter (FD filter) to handle this problem. In Corbae and Ouliaris (2006), the FD filter works by suggesting a frequency domain fix. The authors wrote the second term of (4.10) as

$$w_{\left(\frac{t}{n}\right)}(\theta_k) = \frac{-1}{\sqrt{n}} \left(\frac{e^{i\theta_k}}{1-e^{i\theta_k}} \right) \quad (4.11)$$

Combining (4.10) and (4.11), the Fourier transform of non-stationary variable can be written as:

$$w_{\tilde{x}}(\theta_k) = \frac{1}{1-e^{i\theta_k}} w_v(\theta_k) + w_{\left(\frac{t}{n}\right)}(\theta_k) * (\tilde{x}_n - \tilde{x}_0) \quad (4.12)$$

As the second term in (4.12) shows a clear trend in the frequency domain with a coefficient $(\tilde{x}_n - \tilde{x}_0)$, the FD filter removes this trend in the frequency domain and thus removes the leakage from the low frequency. By using the residuals from the regression (4.12), it leaves an unbiased estimate of the first term. Then applying $\beta(\theta_k)$ to $w_{\tilde{x}}(\theta_k)$ will leave an unbiased estimate of the filtered data. (Corbae and Ouliaris 2006, p.6)

The FD filter uses frequency-domain techniques to extract variations at different frequencies from the time series. The biggest contribution of the FD filter is to extract specific components that do not require any pre-filtering in the time domain. It works well on both trend-stationary data and I(1) data. Though Corbae and Ouliaris (2006)

showed the better performance of FD filter in extracting cyclical components by comparing it with other filters like the HP filter and BK filter, the purpose of my work is not to select a ‘best’ filter to deal with my data. The reason I use the FD filter as the preferred method to do estimation is because of the limits in the methods of AWG (2006b) and the characteristics of the data in UK, as I have described above. In the estimation section, I firstly estimate the reduced-form inflation equation which can give indications on inflation determination. Then I do low-frequency regression and high-frequency regression respectively. In all three types of regressions, the FD filter is used to extract the components at the required frequency band. In order to compare and support my conclusions, the “common approach” in AWG (2006b) to the inflation equation is used as well. To overcome the drawbacks mentioned, I transform inflation and money into the frequency domain first and then take the corresponding trends. For the non-stationary output gap, I take first-differences at the beginning though this is not a good way to avoid leakages completely. When focusing on the long-run relationships among quantity-theoretic variables, Engle’s (1974) method is applied too as the difference between inflation and money is stationary in the UK data. Engle’s band spectral regression, as AWG describe in their work, could be taken as equivalent to filtering the variables and regressing the components at certain frequencies. In the Fourier transform and periodogram estimation process, the components of certain frequencies are calculated by summing up all the information of those frequencies in every observation. Thus the result is expected to be similar to that under the FD filter.

The dividing line between low-frequency and high frequency is 4 years as that in AWG (2006b). The estimation period is from 1975Q3 to 2010Q4. As the definition for broad money is a little different during this period, M4ex, M4 and M3 are used to calculate money growth rates over 1998 to 2010, 1980 to 1998 and 1975 to 1980 respectively. The inflation is the seasonally adjusted CPI growth rate, the interest rate is the bank rate. The supply side shock variables are the import price and effective exchange rate. The output gap is calculated by detrending the GDP from 1975 to 2007 and it is little different from that calculated by using the HP filter. As the GDP has dropped sharply

since 2008, the value of GDP from 2008 to 2010 is not included in calculating the trend. Instead, I extended the previous trend to get the output gap.

4.4. Estimation

This section will show the result of regressions and discuss what relate to the inflation at low frequencies and high frequencies. By comparing the results in two periods, one of which is before the crisis and the other of which includes the data for the last three years, it is expected to find out the difference, especially in the role of money in it.

4.4.1. Inflation and money at different frequency

Before the estimations of inflation regression, let us look at the quarterly change of inflation and money in UK and their spectral density in the frequency domain. Figure 4.1 and Figure 4.2 show the data in both time domain and frequency domain. The quarterly change of inflation used to be high and volatile before the mid-80s. But after that, it remained around 1 percent for twenty years until the crisis in 2008 when it became negative. The quarterly money growth was also higher during the period when inflation was high. Though the fluctuation in money growth recently is not as strong as it was in the 1970s, it is still clear that it has reached a lower level than before since 2008. The latter two graphs describe the periodograms of the variables. The horizontal axis is the frequency of the series and the vertical axis describes its amplitude. For both inflation and money growth, the spectral densities show their peaks at low frequency range around zero and decrease sharply towards high frequency. Figure 4.2 shows that after 0.1π which corresponds to 5 years, the spectral densities keep low. For inflation, there is a small hump around 0.5π though it is much smaller than that at low frequency. This indicates that when inflation is decomposed into different frequencies, most variants and information are contained in the low-frequency component. The fluctuations in inflation are mostly long-run while some are of cycles around 1 year. And the periodograms suggest that the dividing line for long-run and short-run given by AWG (2006b) could also be used in this paper.

The first regression to run is the reduced form Phillips-Curve equation shown in the AWG (2006b) paper, in which the dependent variable is the inflation of all frequencies and the explanatory variables on the right-hand-side are those of different frequencies. As discussed at the beginning, I expected a long-run relationship between money and inflation, as well as the relation with other quantity-theoretic variables. Thus money, GDP growth and the interest rate are expected to explain the long-run term of inflation. Following AWG (2006b), all those variables are extracted from the frequency components longer than 4 years. The equation to show this low-frequency

Figure 4.1: Inflation and money in time domain

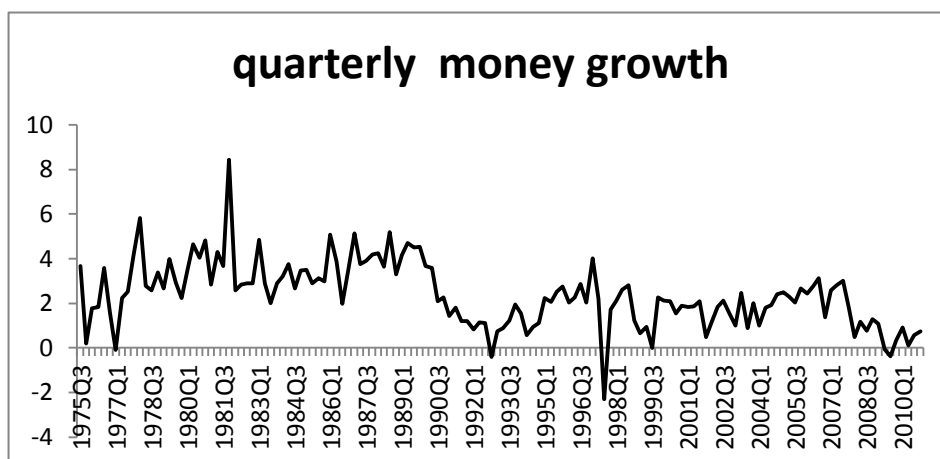
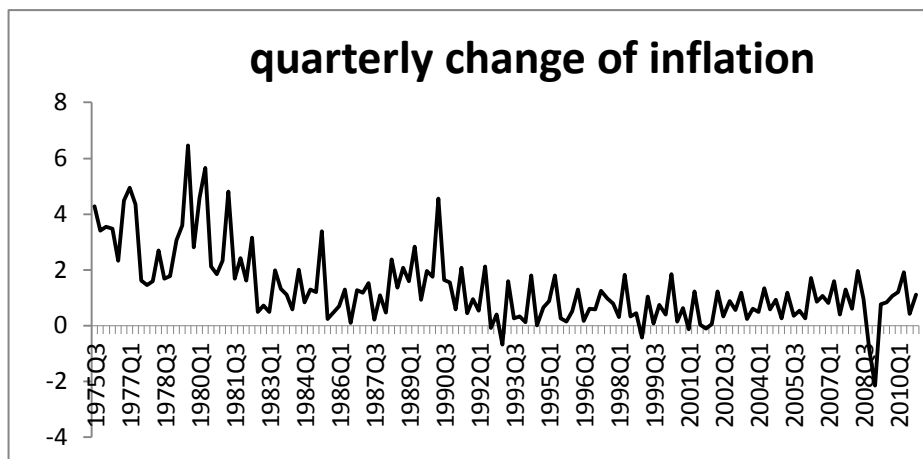
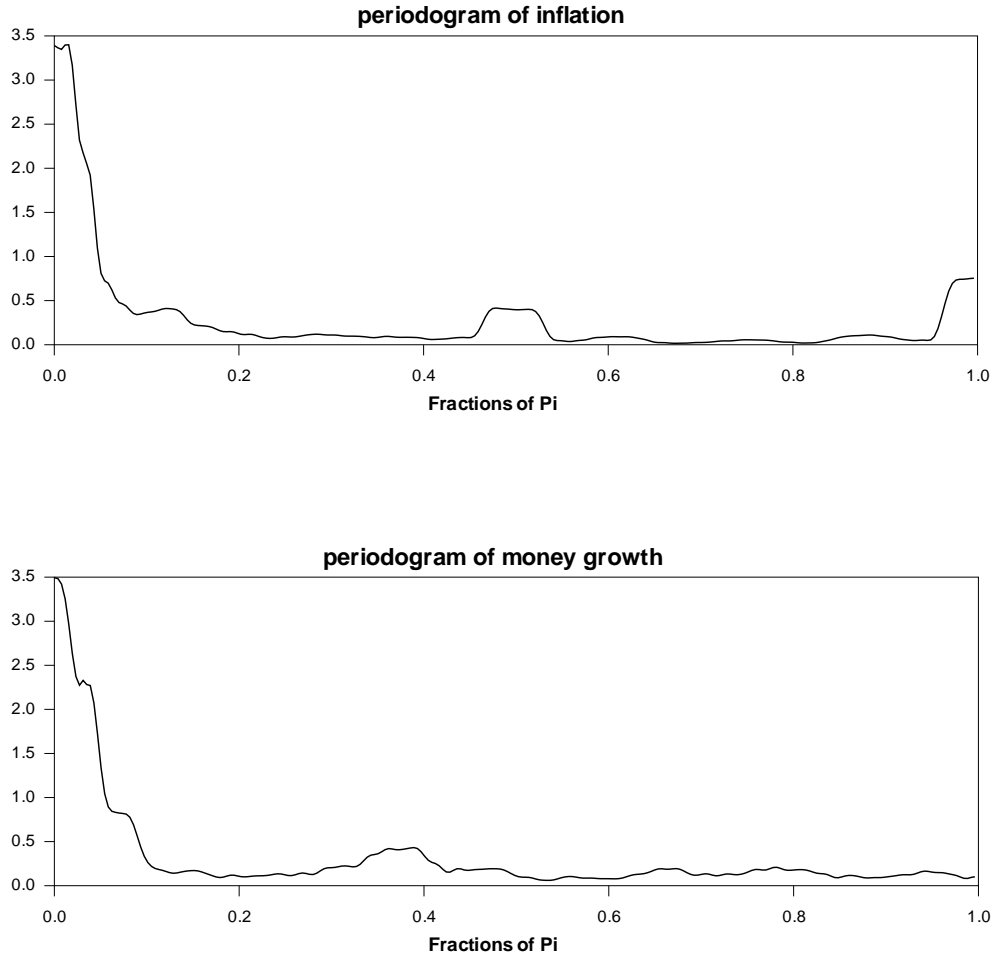


Figure 4.2: Inflation and money in frequency domain



relationship is:

$$\pi^{lf} = \beta_m m_t^{4-\infty} + \beta_\rho \rho_t^{4-\infty} + \beta_r r_t^{4-\infty} + \epsilon_t^{lf} \quad (4.13)$$

On the other hand, the output gap together with cost-push variables is expected to have a high-frequency influence on inflation. The output gap is extracted of the frequency from 1.5 years to 4 years. The cost-push variables are of 0.5 year to 1.5 year frequency which indicates the quickest influence. The high-frequency component of the inflation is expressed as:

$$\pi^{\text{hf}} = \beta_g g_{t-1}^{1.5-4} + \beta_c c_t^{0.5-1.5} + \epsilon_t^{\text{hf}} \quad (4.14)$$

So the regression I am going to estimate is given as:

$$\pi_t = \beta_0 + \{\beta_m m_t^{4-\infty} + \beta_\rho \rho_t^{4-\infty} + \beta_r r_t^{4-\infty}\} + \beta_g g_{t-1}^{1.5-4} + \beta_c c_t^{0.5-1.5} + \epsilon_t \quad (4.15)$$

π_t is inflation of all frequencies, m_t is the money growth rate, ρ_t is the GDP growth rate, g_{t-1} is the lagged output gap, and c_t is the cost-push variable; Figure 4.3 and Figure 4.4 print the frequency components of inflation, money growth and output gap by using FD filter. The series at low frequency are shown in lines while the series at high frequency are shown in dots. Figure 4.3(a) describes the inflation rate and money growth (mgr in the figure) at low frequency. For the whole period, the long-run components of these two series moved in the same direction nearly all the time, which is not clearly shown on the original data. And the money growth was more volatile than inflation all the time. At the beginning of the 1990s when inflation and money growth decreased a lot, money growth fluctuated more. It is the same during the crisis time when QE injected broad money in the economy. However, this head-to-head relation is not clear on the Figure 4.3(b) which describes the short-run components of the two series. The dots are clustered together and it is hard to find a linear relationship. Figure 4.4(a) and Figure 4.4(b) describe the relation between the output gap and inflation. The long-term fluctuations of the output gap are more volatile than those of inflation which makes the relation ambiguous. However the dots are more likely to form a positive relationship.

Figure 4.3(a): Money and inflation at low frequency

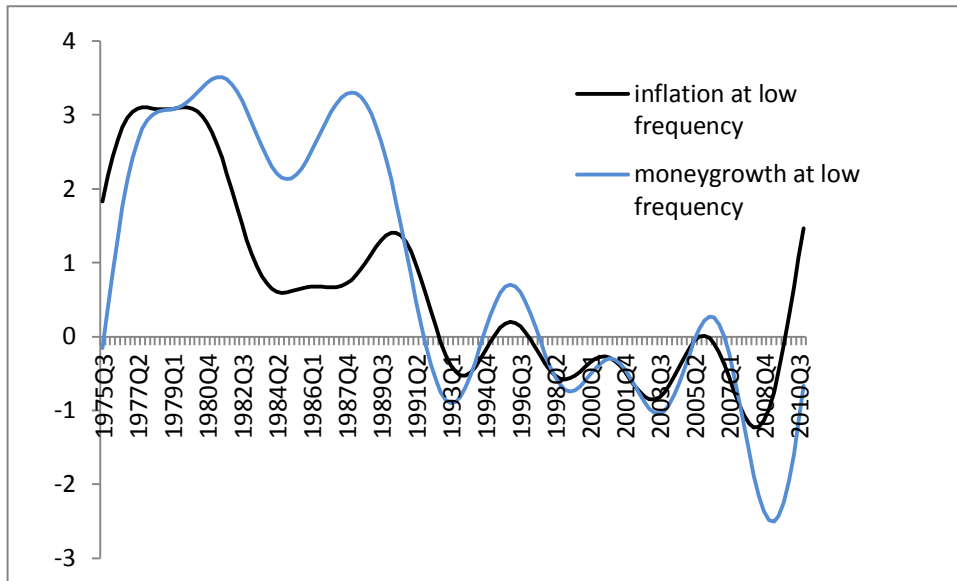


Figure 4.3(b): Money and inflation at high frequency

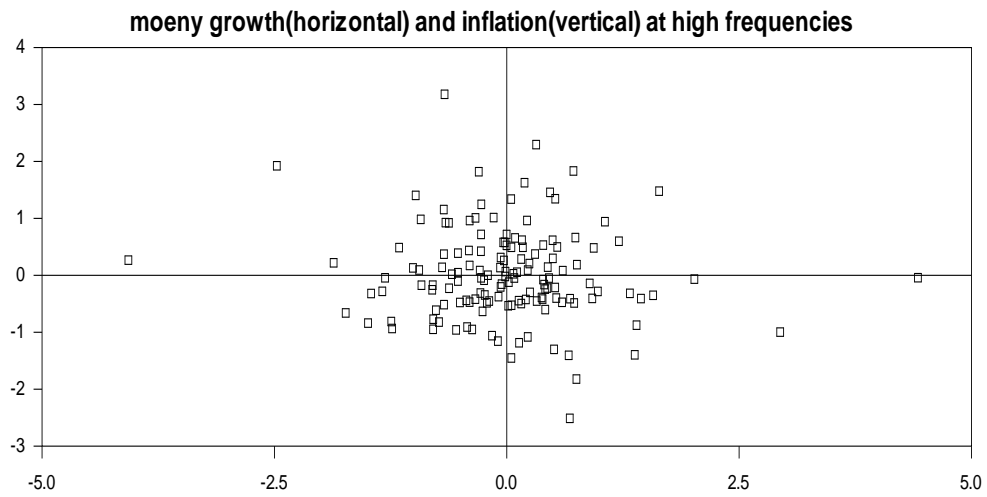


Figure 4.4(a): Output gap and inflation at low frequency

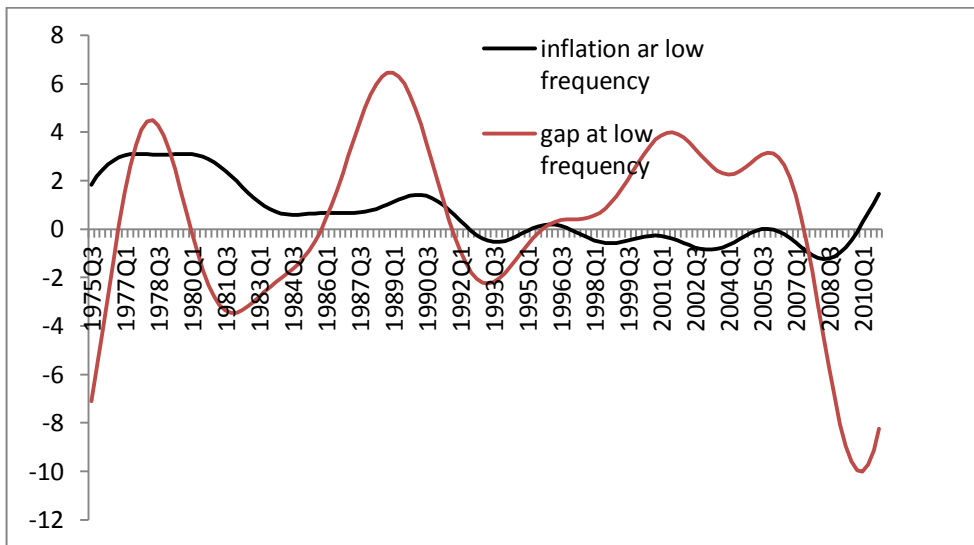
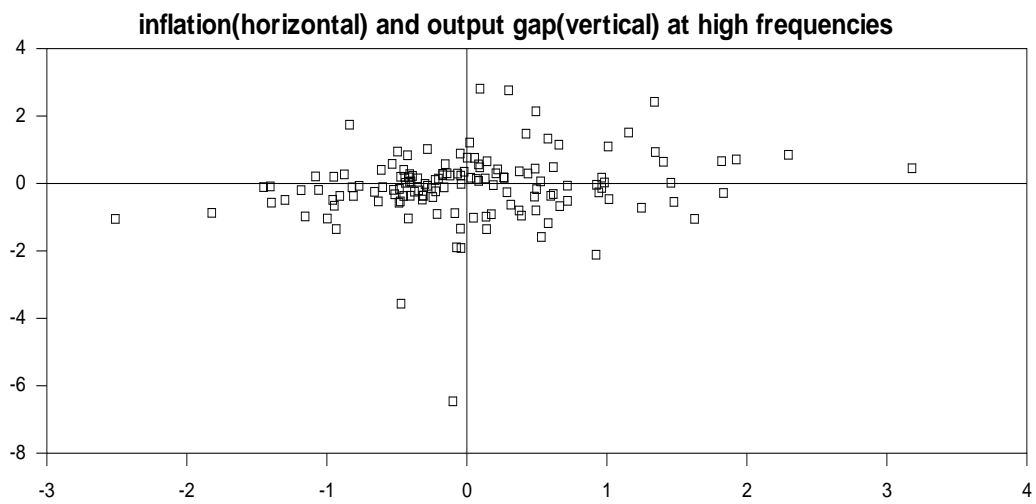


Figure 4.4(b) Output gap and inflation at high frequency



4.4.2. The Phillips Curve Equation estimation

The first estimations of equation 4.15 use UK data from 1975Q3 to 2007Q4 and the results are in Table 4.3. The first column shows the result for a regression in which all variables are at all frequencies. We have a coefficient of 0.164 on the money growth rate which is significantly different from zero at the 95% significance level. This value is much smaller than that found in AWG (2006b) for the euro area though both results are significant. The coefficient on the GDP growth rate is -0.309 and is also significantly different from zero at the 95% significance level. The coefficient on the interest rate change is very small and is insignificant. The output gap has a coefficient of 0.07 which is much smaller than other coefficients in the regression while the coefficients on the two cost-push variables are significantly different from zero at the 99% level and relatively large.

The 2nd, 3rd and 4th columns show the results when the explanatory variables are taken at certain frequencies. The only difference in these three groups of results is the cost-push variable used. The estimates of coefficients on quantity-theoretic variables in these three columns are very similar. The money growth rate has a coefficient of 0.46 which is much higher than the estimate in the all-frequency regression. And it is different from zero at the 99% significance level. The coefficient on the GDP growth rate is still negative and its value is double that in the first column. The coefficient on the interest rate change is still insignificant though the value is much higher. The output gap at the 1.5 years to 4 years frequencies has a coefficient of 0.45 which is significant at the 95% level. It takes more weight in the regression. The cost-push variable, however, is not significant in any regression.

From the results in Table 4.3, it is clear that money growth increases its power of explaining inflation in the long run. When right-hand-side variables are at all frequencies, the movements in cost-push variables have more influence on inflation than the quantity-theoretic variables. Though money has a significant coefficient in the first column, the value of that coefficient is relatively small. When it comes to low-frequency

estimation, money plays a more important role in explaining inflation. The coefficient on money is nearly three times higher than before. The same is true for the GDP growth rate and interest rate change. The coefficient on the GDP growth rate is also much larger in the low-frequency regression. So is that on the interest rate change although the coefficient is still insignificant. However, this does not exclude the possibility that the quantity-theoretic variables, as expected, show long-run relations with inflation which might not be that obvious at all frequencies. The shrinking and insignificant coefficients on the cost-push variables indicate that the high-frequency movements are not as important as low-frequency movements in explaining inflation before the crisis.

Table 4.3: Dependent variable: inflation at all frequencies, (1975-2007,U.K.)

RHS variables	All frequencies	Above 4 years	Above 4 years	Above 4 years
Money growth	0.164**	0.459***	0.459***	0.459***
GDP growth	-0.309**	-0.662***	-0.662***	-0.662***
Rate change	0.005	0.295	0.295	0.295
		1.5to4ys		
Output gap (lagged 1 quarter)	0.074*	0.452**	0.453**	0.454**
		0.5to1.5ys		
Exchange rate change	0.117***	0.058	0.051	
Imp ort price change	0.248***	0.027		-0.016

***: significant at 99% significance level;

**: significant at 95% significance level;

*: significant at 99% significance level;

When the data during the crisis period is included in the regression, the result does not show much difference for the quantity-theoretic variables. Table 4.4 shows the results. The coefficients on money growth, GDP growth and the interest rate change are nearly unchanged and the significance levels are also the same. This suggests that if the crisis period (it is only 3 years' of data in this paper) is included, the role of money growth is unaffected. On the other hand the output gap becomes significant at the 99% level while

it was not significant in Table 4.3. The cost-push variables, however, show a different situation in the crisis period. The coefficient on the high-frequency exchange rate change becomes significantly different from 0 at the 95% significance level. It indicates that the influence of high-frequency movements from the supply side on inflation should not be ignored when the crisis is taken into consideration.

Table 4.4: Dependent variable: inflation at all frequencies, (1975-2010,U.K.)

RHS variables	All frequencies	Above 4years	Above 4years	Above 4years
Money growth	0.160**	0.458***	0.458***	0.457***
GDP growth	-0.214**	-0.639***	-0.639***	-0.639***
Rate change	0.057	0.225	0.224	0.223
		1.5to4ys		
Output gap (lagged 1 quarter)	0.047*	0.342***	0.343***	0.343***
		0.5to1.5ys		
Exchange rate change	0.151***	0.079**	0.067**	
Imp ort price change	0.258***	0.047		-0.012

***: significant at 99% significance level;

**: significant at 95% significance level;

*: significant at 99% significance level;

What is more interesting, the results in Tables 4.3 and Table 4.4 are very similar to what AWG (2006b) got for the euro area. In their results all the quantity-theoretic variables at low frequency have coefficients significantly different from zero, as well as the output gap at 1.5 years to 4 years frequency. The values of the coefficients on the low-frequency variables, in the Euro Area, are higher than what I got for U.K. For the cost-push variables, it is the oil price and import price rather than the exchange rate whose high-frequency movements can be used to explain the inflation in the Euro Area. And the values of the coefficients on the cost-push variables are also smaller than those on the quantity-theoretic variables, which is similar to the findings in this paper.

As the idea of using the frequency-domain technique is from AWG (2006b), it would be

more interesting to estimate the same equations by their method described in section 3 and to see whether it supports the suggestions in the tables above. The main difference between AWG's method and the FD filter is whether it is necessary to pre-filter the data in time domain when there is a non-stationary series. AWG's method requires the data to be stationary or cointegrated. For the data from 1975 to 2007, the Unit-root test in Table 4.1 shows that the series of inflation and money growth are trend-stationary and the output gap is stationary. And the difference between inflation and money growth is also stationary. However, the output gap becomes I(1) if the data after 2008 is included. In this case, the estimation of the period between 1975 and 2007 would contain as much information as the estimation under FD filter while it requires to firstly difference the output gap for the period between 1975 and 2010. This difference could make the output gap stationary as the method required. The results are shown in Table 4.5.

Table 4.5: Estimations using conventional method in AWG

RHS variables	Above 4 years (until 2007)	Above 4 years (until 2010)
Money growth	0.388***	0.488***
GDP growth	-1.214***	-0.859***
Rate change	0.430	0.431
	1.5to4ys	1.5to4ys
Output gap (lagged 1 quarter)	0.604*	0.692**
	0.5to1.5ys	0.5to1.5ys
Exchange rate change	0.063**	0.082***
Imp ort price change	0.034	0.047

***: significant at 99% significance level;

**: significant at 95% significance level;

*: significant at 99% significance level;

By comparing the results in table 4.3 and in the second column of Table 4.5, we can clearly tell that money growth at low frequency and the GDP growth rate at low frequency are still significant at the 99% significance level under AWG's method for the

period between 1975 and 2007. The coefficient of money growth is nearly 0.4 which is a bit smaller than the value of 0.46 under the FD filter method. The coefficient of GDP growth is -1.214 whose absolute value is much larger than that in table 4.3. The interest rate is still insignificant. The output gap is significant at the 90% level and the coefficient is 0.604 which is quite similar to but larger than that in table 4.3. The coefficient of the high-frequency component of the exchange rate change is significant and the value is quite close to that in Table 4.3 while the other short-term variable import price change is still insignificant.

The third column of the table shows the estimation for the period including the crisis period. The coefficient of long-term money growth is still significant at the 99% level and it is larger by 0.1 here. The coefficient of the output gap is also larger and is significant at the 95% level. The difference between this result and the result in the second column is quite similar to the difference between the two estimations under the FD filter method. The long-term money growth has a greater influence on inflation when the crisis period data are included in the estimation. And the output gap shows its impact on inflation especially in the crisis period. The supply side shocks have some influence on inflation but the coefficient is relatively small. The estimation indicates that when the crisis period is considered, the low frequencies of money growth and the high frequencies of the output gap have stronger influence in the determination of inflation.

Though the values of the coefficients are not the same under these two methods, they are already quite close particularly for the coefficients of long-run money and short-run output gap. What we can tell from the frequency-domain estimation, no matter which method is used, is that money growth appears to have some influence on inflation in the long run according to the estimation. So does the short-term component of the output gap.

4.4.3. Estimations at low and high frequency respectively

To further study how money and other variables determine the inflation, I am going to do low-frequency estimation and high-frequency estimation. When studying the determination of inflation in long-run, I put a unit restriction on money and use the difference between inflation and money as the dependent variable, and the frequency band is from 4 years to infinity for all variables. This is equivalent to estimating the equation:

$$(\pi_t - m_t)^{4-\infty} = \beta_0 + \{\beta_\rho \rho_t^{4-\infty} + \beta_r r_t^{4-\infty}\} + \beta_g g_{t-1}^{4-\infty} + \beta_c c_t^{4-\infty} + \varepsilon_t \quad (4.16)$$

The results are shown in Table 4.6.

Table 4.6 : Regression at Low-frequencies, Dependent variable: $\pi_t - m_t$

RHS variables	1975-2007		1975-2010	
	constant	-0.08	-0.11	-0.07
GDP growth	-0.98***	-1.27***	-1.06***	-0.91***
Rate change	-0.07	0.32	-0.27	0.05
Output gap (lagged 1 quarter)		-0.01		-0.10***
Exchange rate change		-0.22**		0.04
Import price change		0.06		0.02
$\overline{R^2}$	0.17	0.21	0.30	0.36

***: significant at 99% significance level;

**: significant at 95% significance level;

*: significant at 99% significance level;

The first and third columns show the regressions which contain only quantity-theoretic variables as explanatory variables. The coefficient on the GDP growth rate is the only one which is significantly different from zero. Its values, -0.98 before and -1.06 after the crisis, are much higher than other coefficients. When other variables at low frequency are included in the regression, the coefficient on the GDP growth rate does not change much. Though the exchange rate and output gap are significant as well, the values of the coefficients are smaller compared with that on GDP growth.

Table 4.7 shows the results for the regression at high frequencies. This time all the variables are used as explanatory variables. The equation to be estimated is :

$$\pi_t^{0.5-4} = \beta_0 + \{\beta_m m_t^{0.5-4} + \beta_\rho \rho_t^{0.5-4} + \beta_r r_t^{0.5-4}\} + \beta_g g_{t-1}^{0.5-4} + \beta_c c_t^{0.5-4} + \varepsilon_t \quad (4.17)$$

The dependent variable is the inflation rate at 0.5 to 4 years and the explanatory variables are also at that frequency. It is clear from the results that whether the crisis period is included or not, none of the coefficients on the quantity-theoretic variables is significant at the 90% significance level. And the values of those coefficients are very small. This suggests that the change in money growth may not have an immediate influence on inflation. Instead, it is the exchange rate change which is significantly different from 0 at the 95% level before the crisis and the 99% level after the crisis. The coefficient on the output gap at high frequencies becomes significant after the crisis. Its value indicates that a 1% rise in the output gap would lead to a 0.35% increase in inflation in the short run, which is much larger than the coefficients on other variables.

Table 4.7: Regression at high frequency

RHS variables	Until2007	Until2010
Money growth	0.034	0.247
GDP growth	-0.001	0.060
Rate change	0.030	0.060
Output gap (lagged 1 quarter)	0.420	0.354***
Exchange rate change	0.059**	0.096***
Import price change	0.046	0.073

***: significant at 99% significance level;

**: significant at 95% significance level;

*: significant at 99% significance level;

By comparing the estimations at low-frequencies and high-frequencies, it is clear that money growth has a direct influence at low frequencies but not at high frequencies. On the other hand, the variables which are not in the quantity theory hardly influence inflation in the long run but have effects in the short run. In particular, the output gap has a more important role in explaining inflation when the data after the crisis is

included. This suggests that during the crisis period, if the output gap is influenced by other variables, inflation in the short run would fluctuate as well. Money growth could be one of these variables. Though it could not affect inflation in the short run, it may have an indirect influence on inflation through its influence on the output gap.

4.4.4. Granger-causality measure

From the estimation results given in previous subsections, it is hard to ignore the long-run relationship between money and inflation. Money growth contains information which can help predict inflation at low frequency. In order to support the findings about the relation between money and inflation further, I use a causality measure which is based on Granger's definition to show the predictive power of money. The frequency-wise causality between money and inflation is shown in Figure 4.5 and Figure 4.6, and the causality between output gap and inflation in Figure 4.7.

Before starting the causality measure, I have to clarify that the causality measure in my work doesn't strictly indicate a causal relationship in the normal, everyday, sense. There is no universal agreement on the definition of causality. People have different conceptions about it. Sims (1972) defined causality by including both lagged values and forward values in the regressions while in Granger's definition the right-hand-side variables of the regressions only include lagged values. What's more, even though the empirical work suggests that variable A explains variable B in future which can't be predicted fully by the lagged values of B, it is still hard to define this simple empirical result as 'causality' without a clear theoretical illustration on the transmission process. Tobin (1970) referred to the conception of 'causality' being used by Friedman and others in empirical work as *post hoc ergo propter hoc*. He argued that Friedman (1956) should not have concluded money causes inflation because the timing of money leads the timing of price. In his (1970) reply to Tobin Friedman carefully explained the conception of 'money causes inflation' as 'changes in money supply account for a large part of variance in nominal income'. According to Friedman's definition, causality refers to a stable association between variables rather than controllability. Thus the

Granger-causality measure in my work is only used to indicate whether money growth indicate inflation at various frequencies.⁵⁴

Granger (1969) defined causality by comparing the predicted errors which are from the regressions of X on past information including/excluding information of Y. (See Granger 1969, p.428). If the variance of the error from the regression that includes past Y is smaller than that from the regression that excludes past Y, we say Y causes X. Under this definition, Granger and Lin (1995) further indicated that the causality relationships could be different between frequency bands.

The method I employ to measure causality under Granger's definition is from Breitung and Candelon (2006). In their paper, the authors developed the causality measure in the frequency domain proposed by Geweke (1982). It is defined as:

$$M_{y \rightarrow x}(\theta) = \log \left[\frac{2\pi f_x(\theta)}{|\varphi_{11}(e^{-i\theta})|^2} \right] = \log \left[1 + \frac{|\varphi_{12}(e^{-i\theta})|^2}{|\varphi_{11}(e^{-i\theta})|^2} \right] \quad (4.18)$$

where $\varphi(L) = \Theta(L)^{-1}G^{-1}$, $\Theta(L) = I - \theta_1 L - \dots - \theta_p L^p$ is the lag polynomial in the bivariate system and G is the lower triangular matrix of the Cholesky decomposition. $\varphi_{12}(L) = -\frac{g^{22}\theta_{12}(L)}{|\Theta(L)|}$ where g^{22} is the lower diagonal element of G^{-1} and $|\Theta(L)|$ is the determinant of $\Theta(L)$.

Geweke (1982) suggested that y does not cause x at frequency θ if $\varphi_{12}(L) = 0$, which means:

$$|\theta_{12}(e^{-i\theta})| = \left| \sum_{k=1}^p \vartheta_{12,k} \cos(k\theta) - \sum_{k=1}^p \vartheta_{12,k} \sin(k\theta) i \right| = 0 \quad (4.19)$$

where $\vartheta_{12,k}$ is the (1,2) element of θ_k , p is the number of lags. And a set of necessary and sufficient conditions for causality is :

$$\sum_{k=1}^p \vartheta_{12,k} \cos(k\theta) = 0,$$

⁵⁴ More issues on causality are discussed in Hoover, Kevin D.(2001), *Causality in Macroeconomics*, published by Cambridge University Press.

$$\sum_{k=1}^p \vartheta_{12,k} \sin(k\theta) = 0 \quad (4.20)$$

Breitung and Candelon (2006) simplified the notation. They suggested that in a bivariate system, the non-causality relation from Y to X at frequency θ is equivalent to a zero restriction on the parameters of Y. The equation for X can be expressed as:

$$x_t = \alpha_1 x_{t-1} + \alpha_2 x_{t-2} + \dots + \alpha_p x_{t-p} + \beta_1 y_{t-1} + \dots + \beta_p y_{t-p} + \varepsilon_{1t} \quad (4.21)$$

The hypothesis of no-causality is equivalent to the linear restriction:

$$H_0: R(\theta)\beta = 0,$$

where $\beta = (\beta_1, \beta_2, \dots, \beta_p)'$ and

$$R(\theta) = \begin{bmatrix} \cos(\theta) & \cos(2\theta) & \dots & \cos(p\theta) \\ \sin(\theta) & \sin(2\theta) & \dots & \sin(p\theta) \end{bmatrix}$$

To test the null hypothesis, a simple F statistic can be used to reflect this causality and it is distributed as $F(2, T-2p)$ in my work. If the value is not significantly different from zero, Y does not cause X at frequency θ . However, as the causality measure varies from low frequency to high frequency, people have more interest in the high values and small values of it, rather than focus on the critical value.⁵⁵

For the money and inflation model, the lags I have included are 12: this is based on AIC values. Figure 4.5(a) shows the causality measure from money growth to inflation when 12 lags are included. The causality measure has relatively high values at low frequency band, as well as at very high frequency band. The two peaks of the causality measure are at 0.15π , which corresponds to 13.3 quarters, and at 0.8π which corresponds to 2.5 quarters. For the frequency band in the middle, the causality measure is relatively low particularly between 0.5π and 0.7π . If we compare the causality measure with the

⁵⁵ Breitung and Candelon (2006) showed the significance of causal relationship following a standard limiting distribution in cointegrated system. AWG (2006) indicated the critical value of F is not that important in their work and they suggested to look at peaks and troughs.

critical value at 10% significance level which is 2.348 here, we can reject the null hypothesis at the frequency band $(0.1\pi$ to 0.2π) and at the band $(0.75\pi$ to π).

Figure 4.5(b) shows the feedback from inflation to money. There are three peaks which are at 0.18π , 0.4π and 0.8π . The values of these three peaks are larger as the frequency goes higher. If we compare the measures with the critical value, we can't reject the null at the frequency band below 0.4π . And we can reject the null at the band 0.4π to 0.45π , and at band 0.8π to π .

According to these results, money growth 'Granger-causes' inflation in a long term which is above 2.5 years and below 5 years. The lower values of the causality measure from inflation to money growth can help indicate that the influence is from money to inflation at this frequency band. Money growth also Granger-causes inflation in the short term of 2.5 quarters and less. The latter result is surprising; it may reflect the higher proportion of noise in monetary growth data at high frequency.

If I shrink the lag length below 12, the AIC values suggest lag=5 at any lag criterion from 11 to 5. The causality measures when 5 lags are included are shown in Figure 4.6(a) and Figure 4.6(b). In Figure 4.6(a), the causality measure from money growth to inflation is much higher at low frequency and it peaks at frequency 0.18π which corresponds to the period around 3 years. Then the causality measure drops fast as the frequency goes to the higher bands. It reaches its trough which is zero at frequency 0.6π and then remains low, so that we do not find here the surprising result noted above. On the other hand, if we focus on the critical value, we can't reject the null hypothesis at any frequency. Figure 4.6(b) also shows stable and low values at the high frequency band. But the peak of the causality is at 0.25π , which is different from that in (a). And we can't reject the null at band 0.2π to 0.3π .

Overall, these results present a mixed picture of the Granger-causality between money and inflation. However, whether the critical values are significant or not does not really tell us whether money 'causes' inflation because of the issues around the meaning of

causality. A full answer to that question would require further work, both conceptual (philosophical) and empirical.

As I have discussed in Chapter 3, some movements in money growth, like the movements under QE, are not automatic responses of the monetary system but are exogenously decided by agents. The evidence from the estimations of Phillips curves and from the causality measure in some sense supports the view that money growth has information in indicating future inflationary pressure, rather than the view that inflation is totally predictable without additional information.

Another important finding on the determinations of inflation is the significant role of the output gap in explaining inflation at the high frequency band which is from 1.5 years to 4 years. The causality measure of output gap to inflation is shown in Figure 4.7 (a). Different from that on money, the causality measure on output gap is relatively low at low frequency and is even zero at frequency 0.07π , around seven years. After that, the causality measure increases towards the high frequency band and reaches its first peak at frequency 0.2π which corresponds to 2 years and half. After frequency 0.6π , which corresponds to 3.3 quarters, the causality measure is also relatively high. Figure 4.7(b) indicates that the Granger-causality from inflation to output gap is only significant below frequency 0.4π .

Besides the causality measure in frequency domain, I also did Granger causality test in time domain. The Chi-sq value for the causality test on money growth to inflation is 18.57 which is significant at 10% level if the lag length is 12, while if the lag length is 5 the value is 2.48 which is not significant at 10% level. For the Granger causality test on inflation to money, we can't reject the null under either circumstance. For the output gap to inflation the test statistic is significant at 1% level so we can reject the null. Overall, the Granger-causality test results, both in frequency domain and in time domain, provide only weak evidence on 'causality'.

Figure 4.5(a) The causality measure on money growth to inflation (lags=12)

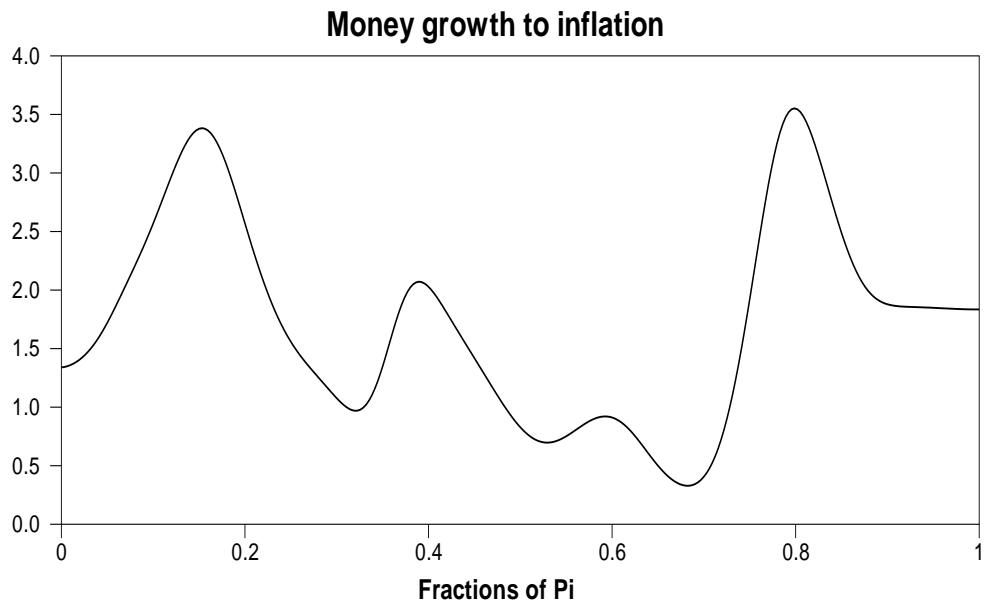


Figure 4.5(b) The causality measure on inflation to money growth (lags=12)

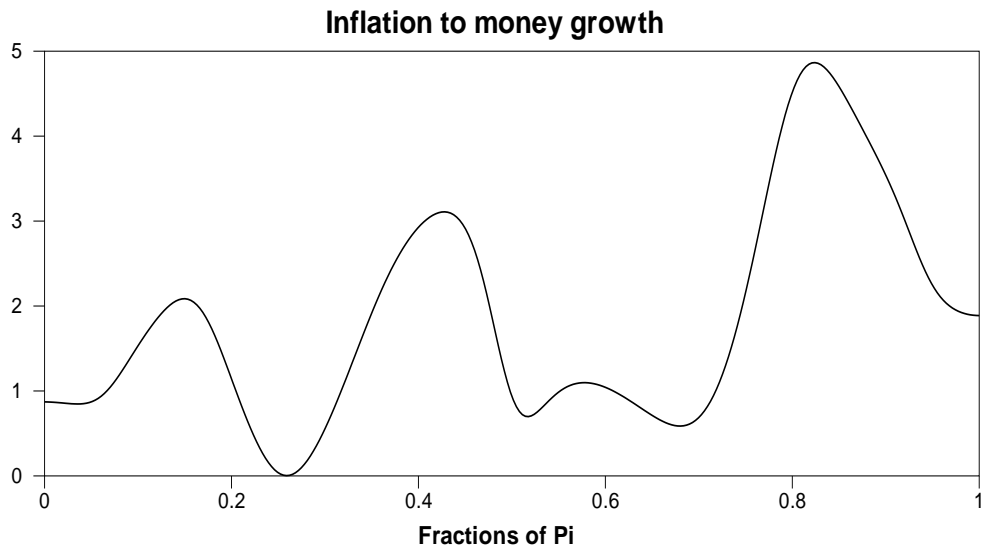


Figure 4.6(a) The causality measure on money growth to inflation (lags=5)

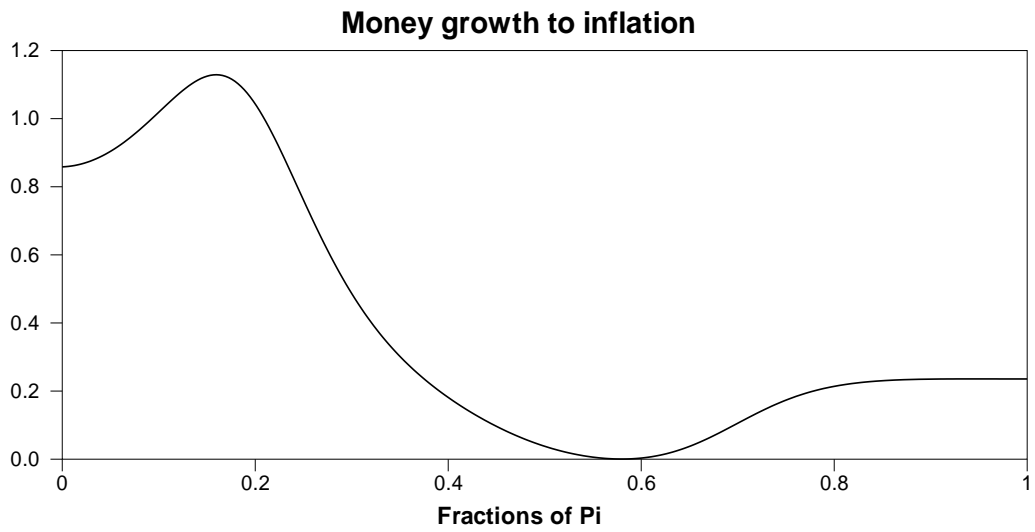


Figure 4.6(b) The causality measure on inflation to money growth (lags=5)

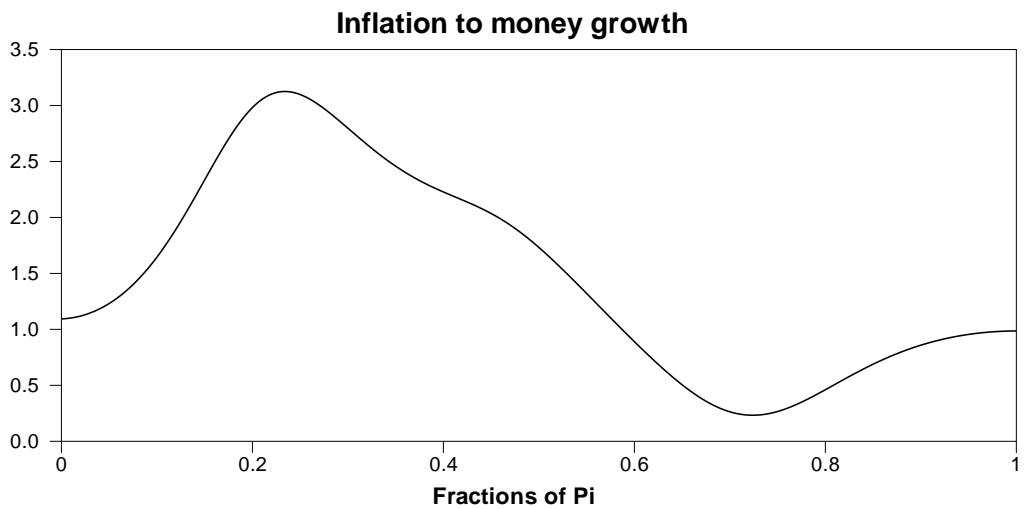


Figure 4.7(a) The causality measure on output gap to inflation

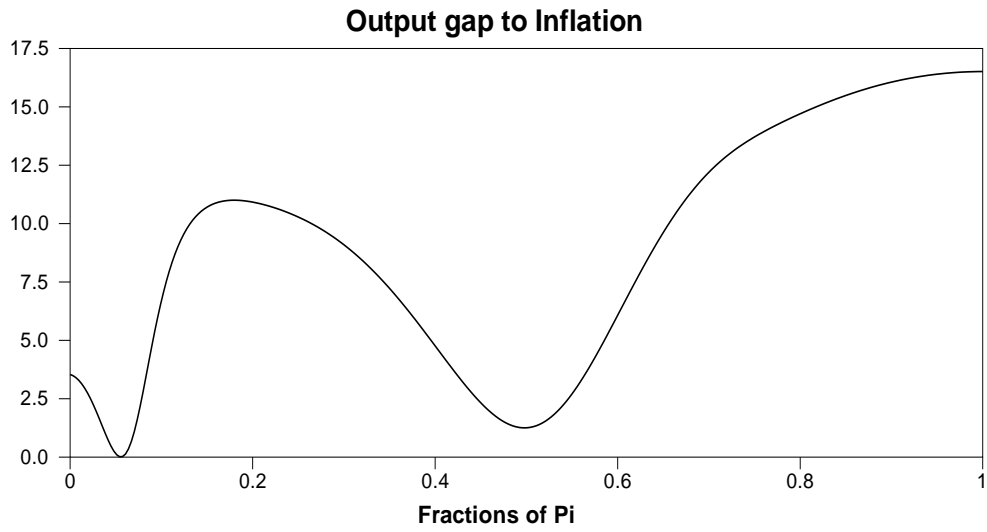
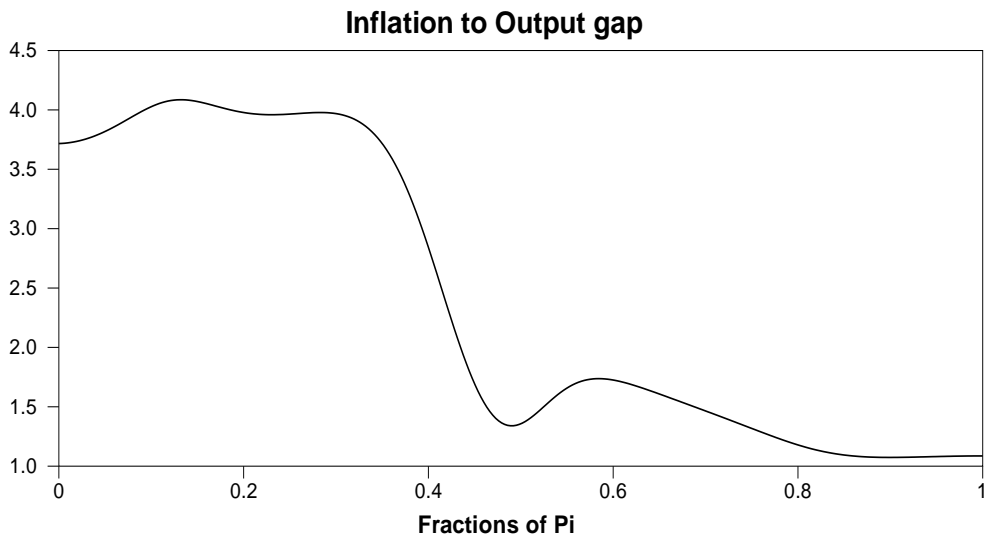


Figure 4.7(b) The causality measure on inflation to output gap



4.5. Conclusions

In this chapter, I discuss the relationship between money and inflation. Most research in the past emphasized that money has a long-run relationship with inflation. By using the Frequency-domain techniques to run Phillips Curve regressions, this paper supports the indication that money should not be forgotten in policy-making decisions. Indeed, from the results, it suggests that the link between money and inflation in long run is stable. This link is never eliminated even during the Great Moderation period when money seemed to be not relevant. Furthermore, the results in this paper did not exclude the possibility of money's indirect influence on inflation. After comparing the relations between inflation and other variables before and after the crisis, I found that the output gap is important in influencing inflation in the short run for the U.K. If a change in money growth could lead to a change in the output gap, it could influence inflation in a relatively shorter period, especially during the present time when inflation is sensitive to the change in output gap and it is hard to cut the interest rate further.

However, the findings that a monetary aggregate has a direct relationship with inflation in the long run doesn't suggest that policy makers should target the monetary aggregate as they used to do in the 1970s. Nor does it suggest the monetary aggregate should enter the reaction function as a separate variable. From the Phillips Curve demonstration in section 4.4.1, money as well as other quantity-theoretic variables enters the equation as components of inflation expectations, or long run components in inflation. Thus, my suggestion is that policy makers should consider the information in money as a necessary part in the inflation expectations which policy is trying to influence. It should not be ignored.

The indications from the estimation could be used to explain Quantitative Easing further. While most research focuses on the effect of QE on the bond market, it might be helpful to think about its influence through the monetary aggregates. As the figure of the M4 growth rate shows, the money growth rate ceased to drop sharply once QE was implemented. From a long-run perspective, the increasing money growth would help

inflation to rise. And even in two or three years' time, which is a relatively short time, the recovery of the M4 growth rate prevents further decline in the output gap. This slowdown in the output gap fall would work on inflation in the short run. In other words, besides interest rate setting, any policy which influences money growth could be used to influence inflation, in both the short run and the long run.

Chapter 5. Conclusion

This dissertation discusses monetary policy in the UK, including the conventional interest rate decisions and the unconventional asset purchases. In the tranquil time before the financial crisis, it suggests that a Taylor-rule type reaction function in which the interest rate responds to inflation forecast two years ahead and output growth one year ahead is a better description of interest rate decisions by the MPC, than the conventional GMM estimation which looks at the current output gap and the inflation one year ahead. Besides, the definition of ‘smoothing’ which is used in some work to describe the interest rate movements should be reconsidered. My finding supports the claims by former policy makers in the Bank of England that there is no smoothing in interest rate decisions. When the crisis began, the central bank conducted QE to achieve its objectives. This dissertation studies the effect of QE on macroeconomic activity. Specifically, it focuses on the direct role of monetary aggregates in activity, which has not been discussed for a long time. The results suggest that money growth can’t be ignored in helping output and controlling inflation. If QE had not been conducted, the output within two years after the first quarter of 2009 might have been much lower than the actual one due to the sharp reduction in money growth. And in the long run, the relationship between money and inflation indicates that it would be difficult to hit inflation targets consistently without considering money.

When I studied the reaction function issue in Chapter 2, I tried to apply the ex ante approach to the ECB’s reaction function. The problem was that there are no explicit staff projections available. Though I used SPF forecasts in place of internal forecasts and also carried out the regression with a different timing as a check, the estimation is still not genuinely ex ante in the Goodhart (2005) sense. The limited number of results did give us some implications. It didn’t support the conventional horizon which is $j=4$ and $k=0$ for the ECB. It preferred longer horizons for both inflation and output, which is close to the empirical work in the book on the transmission mechanism produced by the ECB. The possible reason for this, as I discussed after comparing the two approaches for the BoE case, is that the projections contain some additional information beyond

what is in the instruments used in GMM. The limited instruments in GMM method make it hard to get the actual projections of policy makers. The SPF, though it is more ambiguous than the projections published by BoE, is still much closer to the actual projections. In this way, the estimation for the ECB should also encourage people to apply the ex ante approach if possible.

The latter part of the dissertation is mainly on the effect of QE. I emphasized on whether the change in money growth, which is brought about by QE, has influence on output and inflation. Chapter 3 discusses how money influenced nominal spending in the medium run. Instead of discussing the effect through various financial market yields, I preferred to study the effect of money on spending directly. The flow of funds matrix it was used to illustrate how the change in money in one sector has successive effects on other claims and other sectors. A simple naive regression was then undertaken to estimate this effect. And by constructing different counterfactuals, I have a range for the effect of money change on nominal spending. In addition, I had tried a simple SVAR before I started the regression. Those results, together with the results in other researchers' work, suggest that the change in money has an effect on output though the amount of the effect estimated varies.

Chapter 4 mainly focuses on the long run effect of money change under QE. As price stability is the first objective of the central bank, QE, that is, the change in money is expected to link to inflation. By frequency domain techniques, I tried to explain inflation at different frequencies by different variables. The link between money and inflation is found in the estimation but only in the long run. Besides, the output gap is suggested to have an influence on inflation in the medium run. It indicates that we should always keep an eye on money in the long term. Together with the indications given in Chapter 3, it also suggests that if QE is considered to have effect on the output gap, it also has an indirect effect on inflation.

There are some issues I haven't discussed in this dissertation. For the effect of QE, I only estimate that money has an effect on macroeconomic activity and this effect goes

through all the transmission channels but I don't discuss the micro-economic foundations of how the various sectors optimize their utilities under QE. Other researchers have provided evidence on how QE influences financial market rates, but they have little empirical work on how those yield changes influence output and inflation. Furthermore, since the interest rate has dropped to the effective lower bound, previous models in the last ten years are no longer that satisfactory in explaining the economy now. Maybe a new model should be constructed. In my dissertation, I show some evidence and indications but not from a complex model.

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