Inflation Targeting in an Open Economy: Nonlinearity, Asset Prices and Interest Rates

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Abstract

Inflation targeting has been the central focus of monetary policy since early 1990s as more than 60 central banks across the countries target it explicitly, others target it implicitly. However, how precisely does the central bank target inflation in practice? Does monetary policy always only respond to inflation or does it also react to asset prices and open economy variables? This thesis models these aspects of monetary policy primarily focusing to the UK inflation targeting regime.

The empirical results are significant. First, monetary policy in UK is forward looking. It responds to deviations of inflation from the target, to the output gap and to asset prices misalignments. The policy reaction to inflation is strongest followed by the reaction to the output gap, the foreign interest rate, the exchange rate, house prices and share prices. Second, monetary policy is nonlinear because (a) it has deflationary bias, (b) it responds to asset prices only when asset prices misalignments are high, and (c) it responds to the output gap only when it does not respond to inflation and asset price misalignments. Third, policy response to exchange rates does not depend on inflation regime while the reaction to inflation does depend on the exchange rate regime. Fourth, policy response to inflation is asymmetric and it aims to keep inflation within a range rather than pursuing a point target of 2.5%. Fifth, neither the exchange rate misalignment nor the foreign interest rate alone can capture the open economy effects; policy responds to both variables.

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Chapter 1

Introduction

1.1 An overview of an inflation targeting regime

Although a number of central banks have targeted inflation since the early 1990s, the idea was suggested for more than a century ago. As discussed in Haldane (1995), Alfred Marshall suggested a monetary system that adjusted to fix the purchasing power of each unit of currency closely to an absolute standard as early as in 1887 (Marshall, 1887). Wicksell (1898) advocated an explicit price-level standard for monetary policy that was, later on, implemented by Sweden for about three decades in the beginning of the 19^{th} century (see also Fisher, 1922).

Historically, monetary policy had various objectives across countries until Bretton Woods agreement to the exchange rate stability in July 1944. Under this agreement, member countries were required to maintain the exchange rate of their currency within a fixed value – plus minus one percent – in terms of gold[1]. Following the United States' suspension of convertibility from dollars to gold due to its budget and trade deficits, the Bretton Woods agreement collapsed in 1972.

The objective of monetary policy then gradually refocused to economic stability in general and financial stability including price stability in particular through targeting monetary aggregates (Friedman, 1977). Although some central banks still target monetary aggregates, it did not remain in place for a long time in many countries (IFS, 2005).

Following the failure to stabilize inflation through the exchange rate and monetary aggregates, a growing number of central banks adopted inflation targeting in the early 1990s. There is now a consensus among policymakers, economists, and general public that low and predictable inflation helps to promote economic efficiency and growth in the long run. It is also argued that macroeconomic stability in general and price level stability in particular are important preconditions for economic growth (Fisher, 1993).

It is also accepted that monetary policy can affect only inflation, and not the real variables such as output or unemployment in the long run (Bernanke et. al., 1999). According to this school of thought, one of the reasons for a high level of inflation

[1] This is an agreement on the exchange rate stability made in the United Nations Monetary and Financial conference at Bretton Woods, Washington, in July 1994 by 730 delegates from 44 countries. The agreement, later on, was ratified by other member countries of the UN (Bank of Canada, 2001).

during 1970s and 1980s was the outcome of the attempt to manipulate Philips curve (Philips, 1958). Moreover, Friedman (1977) argues that there is no long run trade-off between inflation and unemployment as expansionary monetary policy results only inflation. The recent speeches of the central bankers and economists suggest that central banks have no choice other than targeting inflation either implicitly or explicitly to keep economy healthier.

Nowadays, more than 60 central banks, both from developed and emerging economies, target inflation explicitly while other targets it implicitly[2] (Mahadeva and Sterne, 2002). This framework of monetary policy aims to achieve an *ex-post* inflation rate. However, as pointed out by Masson et al., (1997), the success of inflation targeting depends on transparency, the ability of the central bank to carry out an independent monetary policy and the absence of a commitment to have another nominal anchors like the exchange rate or to economic growth (see also Bernanke et al., 1999).

1.2 Objective

Although the rate of inflation has remained relatively low and stable in the inflation targeting regime, economic stability is largely influenced by foreign economic shocks and asset price volatility. The contagion effects of the financial and banking crisis during some periods in 1990s, a frequent oil price shocks from the middle-east

[2] See also IFS 2005 Year Book, IMF.

countries, and the development of world financial markets threatened stability. On the domestic front, stock prices and house prices in major industrial countries rose to record levels during this period. These have generated the following lively debates in the literature whether or not monetary policy should and/or does respond to open economy effects and asset prices.

First, the recent literature argues that monetary policy may be nonlinear. This implies that policy does not respond to inflation constantly and uniformly all the time; it may respond to other variables when it does not have to respond to inflation (see chapter 3 for more discussion). For example, Martin and Milas (2004) argue that monetary policy does not respond to inflation when the expected inflation is close to the target. Dolado at el. (2002) argue that policy reaction to the output gap differs between positive and negative output gaps. This class of literature, however, does not describe as how monetary policy behaves when inflation is close to the target or when policy does not have to respond to inflation. Does policy respond to some other variables or remain idle? At the same time, we suspect whether nonlinearity is observed in the literature due to misspecification in the usual Taylor rule.

Second, the literature debates whether monetary policy responds to asset prices. Some argue that asset prices are an integral part of monetary policy and that policy should respond to them in a similar way it responds to inflation and the output gap while others believe that asset prices should be taken into account only to the extent that they help forecasting inflation (see Chapter 2 for references and more discussion).

In either case, the literature, to our knowledge, does not analyze whether policy differ between the periods of a large appreciation and depreciation of asset prices.

Third, there is also a debate on as how monetary policy responds to the open economy. Some papers argue that policy responds to the short-term foreign interest rate while others argue that it responds to the real exchange rate or the real exchange rate misalignment as an alternative to the foreign interest rate (see Chapter 3 and 4 for the references and more discussion).

In this context, we investigate some of these issues discussed above. In particular, the main aim of this research is

(a) to investigate whether monetary policy responds to asset prices. If so, to what extent and whether the policy response depends on the state of inflation?

(b) to assess whether monetary policy targets inflation precisely in a way it is announced. In the process we analyze whether policy is forward or backward looking, linear or nonlinear, point target vs. range target, symmetric vs. asymmetric; and

(c) to analyze whether monetary policy responds to foreign interest rates and real exchange rate misalignments; and whether the policy reaction to them depends on the state of inflation.

1.3 Major findings

The analysis begins with an investigation of whether or not monetary policy responds to asset prices. We consider two approaches in this regard. We first assess whether policy responds to asset prices collectively by responding to the financial condition index (FCI) in chapter 2 and we then verify the findings of chapter 2 by estimating an asset prices augmented Taylor rule in chapter 3.

In chapter 2, we construct FCIs, which are a weighted average of the interest rate, the exchange rate, share prices and house prices. Instead of using a demand curve for obtaining FCIs as in the conventional literature, we propose that an open economic structural model be used. We provide two alternative weighting procedures, one for a strict CPI inflation targeting framework and another for a flexible inflation targeting framework.

We construct FCIs for the US and the UK using quarterly data over 1979Q1 to 2003Q4 and then estimate a FCI augmented Taylor rule. Our empirical results show that FCIs are very useful for describing the monetary policy stance in these two countries.

We then estimate asset price augmented reaction functions in Chapter 3 as an alternative to the FCI augmented Taylor rule in Chapter 2. The asset prices we consider in this chapter are similar to those of chapter 2 as we use exchange rate misalignment, deviations of house prices from trend and deviations of share prices from the fundamental. Our results overwhelmingly suggest that the asset price augmented Taylor rule outperforms a simple rule. Overall, we obtain a consistent conclusion from both chapters (chapter 2 and 3); monetary policy responds to asset prices.

Chapter 3 also aims to investigate whether or not monetary policy is nonlinear and whether or not it responds to exchange rate misalignments. It employs various nonlinear models including the smooth transition autoregressive (STAR) model to asses nonlinearity in monetary policy. Chapter 4 further models UK monetary policy using three regimes STAR model. This chapter mainly seeks to analyze whether monetary policy responds to foreign monetary policy by responding to the foreign short-term interest rates. As we find that the BoE responds to the exchange rate misalignment in chapter 3 and to the foreign interest rates in chapter 4, we then include both variables in the reaction function in chapter 5 and employ a four regime STAR model. The empirical findings can be summarized as follows:

First, we find that monetary policy is forward looking. The empirical estimates throughout this research constantly suggest that one quarter ahead forward looking Taylor rule outperforms any other specification.

Second, the policy reaction to inflation is strongest followed by the response to the output gap, the foreign interest rate, the exchange rate, house prices and share prices.

Third, we find that policymakers aim to keep inflation within a range rather than pursing a point target in practice.

Fourth, monetary policy does not respond to inflation when the expected inflation is less than the lower threshold. On the other hand, the policy response to inflation is vigorous when expected inflation exceeds the upper threshold. These imply that monetary policy is deflationary bias. Moreover, we find that the upper inflation threshold is just slightly higher than the target of 2.5% but the lower threshold is far below the target though the BoE has to give a formal clarification to the government if inflation deviates for more than 1% in either direction from the target, suggests monetary policy is nonlinear and policy response is asymmetric.

Fifth, monetary policy in the UK considers a separate exchange rate regime together with inflation regime. The BoE responds to inflation and exchange rate only when they are in their outer regime. More precisely, the Bank responds to the exchange rate only if domestic currency under-valuation is greater than 4% or over-valuation exceeds 5%. Similarly, policy responds to inflation only when expected inflation is less than 1.9% or greater than 2.8%.

Sixth, the monetary policy response to exchange rate misalignments does not depend on inflation regime but the response to inflation does depend on the exchange rate regime.

Seventh, policymakers respond to the output gap only when they do not respond to asset prices or inflation, that is, when inflation and the exchange rates are in their inner regimes.

Finally, we find that neither the exchange rate misalignment nor the foreign interest rate alone can capture the open economy effects; monetary policy responds to both variables. Unlike the policy response to exchange rate misalignments, we find that policy reaction to the foreign interest rate is unaffected by the inflation or the exchange rate regimes.

Although we use a standard analytical framework of monetary policy, our findings should be taken cautiously while generalizing them for the following reasons:

First, it is argued that the performance of inflation targeting depends on the institutional framework, operational procedure and the development of money and financial markets, (see Bernanke et al., 1999). Therefore, our findings may not be generalized to other central banks if the policy environment is different from that of the BoE.

Second, the literature explores various policy rules to be employed to assess monetary policy. Following the monetary policy committee (MPC) minutes of the BoE, we rely on the interest rate reaction functions and do not attempt to compare them to any other alternative policy rules[3] (Taylor, 1993, 1999 and Clarida et al, 1998). Our analytical framework, therefore, can not be generalized to other countries if the interest rate rule is not applicable to them.

Third, we do not make any argument as to whether or not monetary policy should respond to asset prices and the international market as the literature debates this issue. Our main focus is to analyze whether or not policy has been responding to them in practice.

Fourth, there are numbers of crucial issues on the topic such as range target vs. point target; price level vs. price changes target; impact of institutional autonomy to the performance of inflation targeting; the definition of inflation to be considered; and the criterion for setting the target range/value. We, however, do not attempt to address any of them. We begin our analysis on the assumption that the central bank is free to set monetary instruments to achieve the quantitative target which is already well defined.

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[3] For example, some studies strongly advocate nominal income growth rule and monetary targeting rules as an alternative to the interest rate rule (Taylor, 1999).

Chapter 2

Monetary Policy, Asset Prices and Inflation Targeting: An Aggregate Approach

2.1 Introduction

If the interest rate is the only effective monetary policy instrument in an open and liberal economy and if inflation target is the only objective of monetary policy then why be the central bank not just follow the Taylor rule (Taylor, 1993, 1999) to respond inflation? In practice, a number of monetary transmission channels work together which may have a direct or indirect impact on inflation with differing magnitudes. This implies that a proportional relationship between the interest rate and inflation may not hold due to an involvement of other variables, possibly asset prices. For instance, if overall economy is growing at above trend pace in a period of low inflation, there would be a policy mistake if the interest rate is lowered in response to inflation (see also Dudley and Hatzius, 2000; Goodhart and Hofmann, 2001, 2003 among others).

A large bulk of literature, therefore, argues that the simple Taylor rule is suboptimal in an open economy because it does not consider the exchange rate and other asset prices in the policy framework (see Ball 1999 and references therein). In fact, monetary policy might take account of open economy effects and domestic financial markets by responding to exchange rates, property prices and equity prices respectively at least for three reasons. First, asset price misalignment may jeopardize financial stability, which in turn may distort output and inflation (Goodhart, 2001 and Lowe, 2002). Second, asset prices play an important role in the transmission of monetary policy. For instance a rising asset price may have a direct impact on aggregate demand because asset prices are associated with growing inflationary pressure (Montagnoli and Napolitano, 2005). Third, asset prices contain important information regarding the future path of inflation and output (Goodhart and Hofmann, 2003, Kontonikas and Ioannidis, 2005).

As discussed, there is a consensus in the literature that asset prices play an important role in the economy. What is debatable is how and to what extent should monetary policy respond to asset prices? There are three different views regarding this. The first view is that asset prices should be made an integral part of monetary policy. Policy should respond to them in a way it responds to inflation and the output gap (Cecchetti et al., 2000). The second view is that asset prices should be considered only to the extent that they help in forecasting inflation. As asset prices, in general, are more volatile than output and inflation, monetary policy may not be able to control inflation if it responds to asset prices (Bernanke and Gertler, 1999). Finally, there is an argument that policy should target a broader price index that includes asset prices (Goodhart, 1999; Goodhart and Hofmann, 2003). Targeting a broader price index in a way of targeting CPI inflation implies that policy responds to both inflation and asset prices (Duguay, 1994).

To construct this broader price index, Freedman (1994), Duguay (1994) and Ball (1999) propose a weighted average of the short-term interest rate and the exchange rate that we know as the monetary conditions index (MCI). Under this approach, policymaker attempts to set interest rates in order to keep the MCI in a par level or within a range so as to maintain inflation and output[4]. However, this index still potentially neglects other transmission channels of monetary policy except for interest rates and exchange rates.

In order to include domestic asset prices in the policy framework, Goodhart and Hofmann (2001) develop a financial conditions index (FCI). This is a weighted average of the short-term real interest rate, the real exchange rate, real house prices and real share prices. This index is an extension of the MCI that includes house prices and share prices in addition to MCI variables. Keeping the FCI in a specified range or

[4] Since MCI keeps a strong positive relationship with inflation (Freedman, 1994).

at a par level, therefore, implies that the central bank is also responding asset prices in order to stabilize the inflation and output (Gauthier et. al., 2004).

In the light of this discussion, this chapter aims to give a different look regarding the aggregate approach of monetary policy by introducing alternative measurements for FCI. Our motivations are the following.

First, the existing literature uses only the IS curve to obtain weights of asset prices (eg.Goodhart and Hofmann, 2003, Lack, 2003) and excludes the supply side of the economy. We argue that the FCI should be obtained from a macroeconomic structural model, which combines both the supply and demand factors in the determination of inflation and output.

Second, the conventional literature does not take into account of the direct impact of changes in the real exchange rate while determining the FCI weights. We argue that import prices may play a role in the determination of inflation in an open economy.

Third, the literature does not analyze whether the FCI framework is designed to target the CPI inflation or other measure of inflation. We argue that the construction of FCI weights should reflect the type of inflation that is targeted by the central bank.

This chapter addresses these issues on both theoretical and empirical grounds. We develop two alternative FCI models, one for CPI inflation and another for domestic inflation targeting frameworks respectively. Although both of them are obtained from a macroeconomic structural model, the main difference between them is the treatment of the real exchange rate. The CPI model assumes that the real exchange rate has a direct impact on inflation via import prices and indirect effects via pressure on the aggregate demand while the latter case considers the indirect impact alone.

Second, we construct FCIs for the UK and the USA using our new methodology and compare them with the conventional method. The usefulness of indices is, then, tested by estimating the FCI augmented Taylor rule. The empirical results overwhelmingly suggest that the FCI contains important information for the monetary policy setting. Finally, we find that the FCI augmented Taylor rules outperform the simple rule in both countries irrespective to the type of FCIs, implies that monetary policy responds to asset prices.

The rest of the chapter is organized as follows. Section 2.2 reviews the existing literature. Section 2.3 presents the theoretical model. Section 2.4 computes MCI/FCIs for the UK and the USA. Section 2.5 estimates simple and the FCI augmented Taylor rules. Finally, section 2.6 concludes the chapter.

2.2 Literature review

2.2.1 Monetary transmission channels and asset prices

Monetary policy affects the real economy via a number of channels. The interest rate channel has traditionally been the focus of monetary policy, especially in a closed economy. In the case of open economy, however, the conventional Taylor rule is considered to be suboptimal since it neglects other transmission channels including the exchange rate channel (Ball, 1998). It is argued that the exchange rate has a twin effect on inflation – it affects it directly via the import price channel and indirectly via its impact on domestic demand (Guender 2001b, Guender and Matheson, 2002).

Moreover, recent empirical research on the monetary transmission mechanism indicates that property prices and equity prices also play an important role, through the wealth channel and the credit channel respectively (eg. Goodhart 2001, Borio and Lowe, 2002). The former channel exists when a change in asset prices affects the financial wealth of individuals and leads to a change in their consumption decisions (eg. Modigliani, 1971). The latter channel appears when a rise in asset prices increases the borrowing capacity of individuals and firms by expanding the value of their collateral (eg. Bernanke and Gertler 1999). These changes in consumption decisions or borrowing capacities affect inflation via its impact on aggregate demand.

The literature offers various alternative options that asset prices can be included in the conduct of monetary policy. Bernanke and Gertler (1999, 2001) argue that movements of asset price misalignments contain important information for predicting future inflation but there is no feed back role of monetary policy to maintain asset prices around their fundamentals. They argue that cost of responding to assets price misalignments might be higher than the benefits, especially in the bubble period. More specifically, Filardo (2001) argues that if the policymaker responds to assets prices, they will induce a high volatility in the interest rate which may jeopardize inflation targeting. Therefore, they argue that there is almost no role of assets prices in the conduct of monetary policy even though they contain important information about future inflation and output.

A seminal work by Alchian and Klein (1973) and later by Goodhart and Hofmann (2001) offers a clear argument why the central bank should consider asset prices in the conduct of monetary policy. They argue that asset prices reflect current consumption and current money prices of future claims as their inclusion in the determination of inflation is inevitable. Cecchetti et al. (2000) and Borio and Lowe (2002) further argue that policymakers concerned of stabilizing inflation are likely to achieve superior performance by responding to asset prices along with output and inflation.

Since exchange rates, house prices and share prices are not policy instruments, the monetary authority can only respond to them through the available monetary instrument, i.e. the interest rate. Therefore, the channel through which asset prices enter in the monetary policy framework and the way in which policymakers respond to them are crucial issues.

The literature describes two alternative frameworks through which the authority can address asset prices in the conduct of monetary policy. The first framework is the construction of an open economy Taylor Rule by including all assets prices in the reaction function. In this case, the authorities set interest rates in response to deviations of inflation from the target, the output gap and deviations of assets prices from their fundamental or equilibrium levels[5] (Smets, 1997).

The second framework is to formulate an FCI augmented policy rule in which case the authority responds to the FCI in a way it responds to deviations of inflation from the target and the output gap. In this case, policy responds to asset prices collectively by responding to FCIs (Gauthier et al, 2004, Goodhart and Hofmann (2001, 2003).

2.2.2 The definition and construction of FCI

As discussed, the literature identifies at least four channels (the interest rate, exchange rate, credit and balance sheet channels) through which the effects of monetary policy

[5] See Section 2.5 for more discussion.

are transmitted to the real sector (Goodhart, 2001, Goodhart and Hofmann, 2001). The FCI combines these transmission channels together. Generally, it can be defined as a weighted average of deviations of asset prices from their equilibrium or reference period. Therefore, a rise in FCI can be interpreted as contractionary monetary policy stance while a fall indicates an expansionary[6] (Lack, 2003).

Following Goodhart and Hofmann (2001, 2003), the FCI can be defined as:

$$FCI_t = \sum_{i}^{n} w_i (q_{it} - \overline{q_i}), \tag{2.1}$$

such that: $$\sum_{i}^{n} w_i = 1 \tag{2.2}$$

Where, q_{it} is asset price i and t indicates the time period. $\overline{q_i}$ is the long run trend or equilibrium value of asset i and w_i is the relative weight given to asset i. The interpretation of Eq. (2.1) depends on three components - the number and type of asset prices, q_{it}, definition of the equilibrium price, $\overline{q_i}$ and the weights, w_i. The following sections describe each of them in a greater deal.

[6] Assuming a rise in the exchange rate indicates appreciation of national currency vis-à-vis foreign currencies.

2.2.3 The use of variables in an FCI

A survey of the literature presented in Table 2.1, shows that the real interest rate and the real exchange rate are commonly used in the construction of the MCI. Besides the MCI variables, Goodhart and Hofmann (2001, 2003) and Mayes and Viren (2001) include real house prices and real share prices in the construction of the FCI for Europe, USA and Japan. On the other hand, Lack (2003) constructs FCIs for Switzerland using only three variables – the real interest rate, the real exchange rate and the real house price. Gauthier et al. (2004) obtain a broad based FCI for Canada. They include long-term interest rates and the corporate bond risk premium in addition to the four variables proposed by Goodhart and Hofmann (2001, 2003).

Instead of using house prices and share prices, there is also a practice of using alternative financial variables to represent the credit and balance sheet channels. For instance Macroeconomic Advisors (1998) use the dividend price ratio and household equity wealth. Carmichael (2002) and Goldman and Sachs (2000) include the yield curve and the money supply as financial variables in their FCIs.

2.2.4 Defining equilibrium asset prices

The literature offers two types of interpretations of an FCI depending upon the definition of $\overline{q_t}$. When $\overline{q_t}$ is defined as the value of any reference period of asset i, then $q_{it} - \overline{q_i}$ measures a deviation of asset price i from that particular reference period. In this case FCI can be interpreted as a change in financial stance from a given particular time where a positive deviation indicates contractionary while negative deviation implies accommodative policy change (see Goodhart and Hofmann, 2003 and Lack, 2003 among others).

Alternatively, when $\overline{q_i}$ represents an equilibrium value or the long run trend of asset i, then $q_{it} - \overline{q_i}$ measures a deviation of asset i from equilibrium. In this case, the FCI can be interpreted as a deviation of financial stance from the equilibrium. This class of FCIs can be found in Goodhart and Hofmann (2001), Montagnoli and Napolitano (2005) and Degrer (2003).

More specifically, Goodhart and Hofmann (2001) use the sample mean to represent the trend value for the real interest rate, a linear trend for real exchange rates and real house prices. They employ Hodrick Prescott trended method to obtain the equilibrium value of share prices. Montagnoli and Napolitano (2005) use Kalman Filter while Degrer (2003) use a partial equilibrium model to obtain the equilibrium value of asset prices for the Swedish FCI.

Table 2.1: The composition of the FCI in the literature

Study\Variables	Short term interest rate	Long term interest rate	Exchange Rate	Equity Market	Other Variables
Banque de France~	3-month market rate	10-year Govt. Bond	Real effective		
Mayes and Viren (2001)	Real 3-month market rate		Real bilateral vs. U.S.	Real stock Price	Real house price
Goldman Sachs~	Real 3-month market rate		Real effective	Measure of stock valuation	Yield curve
Goldman Sachs (1999)	Real 3-month LIBOR	Real A-rated corporate Indexed	Real trade weighted	Equity market cap/GDP Ratio	
J.P. Morgan $	Real 3-month market rate	10-year corporate spread	Nominal C-6	Nominal TSX index	Yield curve, M1 and M2*
Macroeconomic Advisers (1998)~	Real FED funds rate	Real 10-year Treasury Yield	Real	Dividend/ Price Ratio, Household equity wealth*	
Goodhart and Hofmann (2001)	Real 3-month market rate		Real effective	Real stock price	Real property price
Goodhart and Hofmann (2003)	Real short term interest rate		Real effective	Real stock price	Real property price
Lack (2002)	Real 3-month LIBOR		Real trade weighted		Real property prices
Gauthier et.al.(2004)	Real 90-day commercial paper rate	Real 10-year govt. bond	Real C-6 exchange rate	Real S&P 500 Stock index,	Real house price, US. High-yield risk spread
Degrer (2003)	Real short term	Real long term	Trade weighted	Real stock price	Real house price
Montagnoli and Napolitano (2005)	Real short term interest rate		Real effective	Real stock price	Real property price

*Note: ~ source: Gauthier et.al. (2004). * Alternatively used*

Contd…

Study\Variables	FCI constructed for	Variables modelled as	Sources of FCI Weights
Banque de France~	G-7 countries	Change from a base period	IMF's and OECD's Macroeconomic model
Mayes and Viren (2001)	17 countries	Level of real interest rate and exchange rate; first difference of the rest	IS curve (single equation)
Goldman Sachs~	Canada	Unknown	Simple average
Goldman Sachs (1999)	USA	Deviations from historic mean	FED macro model
J.P. Morgan $	Canada	Deviation from mean divided by variance	Simple average
Macroeconomic Advisers (1998)~	USA	Not specified: referred to as "technical adjustment"	Washington University Macro model
Goodhart and Hofmann (2001)	G-7 countries	Deviation from trend: long run mean for interest rate, linear trend for exchange rate and house prices; and HP filter for stock price	1. reduced form IS and Philips curve model. 2. Impulse functions of a VAR*
Lack (2002)	Switzerland	First difference of variables	Shocks to restricted and structural macro model*
Goodhart and Hofmann (2003)	USA, UK, Japan, EU	Level for real interest rate and real exchange rates and first difference for house and share prices	Single equation IS curve
Gauthier et.al. (2004)	Canada	First difference and HP filtered*	Single equation (IS curve), VAR generalized impulse response function and factor analysis**
Degrer (2003)	Sweden	Partial estimate of each variable	VAR impulses
Montagnoli and Napolitano (2005)	USA, UK, Canada, EU	Kalman Filter	Single equation IS curve

*Note: ~ source: Gauthier et.al. (2004). *: two scenarios are presented*
*$ Source: Carmichael (2002) **: Three scenarios calculated.*

2.2.5 Weigh calibration process

There are at least five methods to obtain weights for asset prices, w_i (see Goodhart and Hofmann, 2000 and Gauthier et al. 2004). They are:

- Simulation of a large-scale macroeconomic model
- Small scale macroeconomic models
- Aggregate demand model
- VAR impulses-response function
- Factor analysis

Large scale macroeconomic models capture the structural features of the entire economy. Goldman and Sachs (1999) and Macroeconomic Advisers (1998) use such a large-scale model to obtain weights for FCI components. Although a large-scale model incorporates all necessary information while predicting weights, the literature argues that they are less useful in practice for two reasons. First, Gauthier et al. (2004) argue that stock prices and share prices play a limited role in many large-scale macro models currently used by central banks so that weight generation from this process may underestimate the actual role play by these variables in the economy. Second, Goodhart and Hofmann (2001) believe that a large-scale macro model with an explicit role for property price is still unavailable.

The second option is to employ a small-scale macroeconomic model. A typical small-scale macroeconomic model consists of a Philips curve and an IS curve. Following Goodhart and Hufmann (2001) and Gauthier et al. (2004), a simple macroeconomic structural model can be written as:

$$\pi_t = k_1 + \sum_{i=1}^{n} k_{\pi i}\pi_{t-i} + \sum_{j=1}^{n} k_{yj} y_{t-1} + \eta_t \qquad (2.3)$$

$$y_t = b_1 + \sum_{i=1}^{m} b_{yi} y_{t-i} + \sum_{j=1}^{m} a_{rj} r_{t-j} + \sum_{j=1}^{m} a_{ej} e_{t-j} + \sum_{j=1}^{m} a_{hj} h_{t-j} + \sum_{j=1}^{m} a_{sj} s_{t-j} + \varepsilon_t \qquad (2.4)$$

Equation (2.3) is the Philips curve and (2.4) is the IS curve where π is inflation, y is the output gap, r is the real interest rate, e is the real exchange rate, h is the real house price index, and s is the real share price index. The last variable of each equation is the error term which is assumed to be mutually uncorrelated with zero mean and constant variance and finally other remaining terms are unknown parameters to be estimated.

In this framework, the relative weights, W_i, which appear in the construction of an FCI, can be written as:

$$W_i = \frac{\sum_{j=1}^{m} a_{ij}}{\sum_{j=1}^{m} a_{rj} + \sum_{j=1}^{m} a_{ej} + \sum_{j=1}^{m} a_{hj} + \sum_{j=1}^{m} a_{sj}} \qquad \text{for i} = \{r,e,h,s\} \qquad (2.5)$$

One of the criticisms of this approach is that it assumes the closed economy Philips curve that excludes the direct impact of exchange rate on inflation. Ball (1999), Guender (2001a) and Guender and Matheson (2002) argue that changes in the real exchange rate should be included in the Philips curve to measure the direct impact of exchange rates.

The third and most commonly used approach is to derive the FCI weights from the IS curve, i.e. Eq. (2.4). This approach explicitly believes that inflation solely depends on the output gap. Goodhart and Hofmann (2003) and Mayes and Viren (2001) generate FCI weights while Duguay (1994), Mayes and Viren (2000), among others, compute MCI weights based on this approach. It is, however, argued that FCI weights obtain from this model may not reflect the economic conditions as it potentially neglects the supply side of economy (eg. Guender and Matheson, 2002).

The fourth method given in the literature is the vector auto-regression (VAR) estimation. Initially, Goodhart and Hofmann (2001) and later on Gauthier et al. (2004) explore the reduced-form approach to a VAR technique. Under this method, they obtain alternative weights of all asset prices based on the impulse responses of inflation to asset price shocks in an identified VAR. They identify the shocks using a standard Cholesky factorization with ordering output gap, inflation, real house prices, real exchange rate, real interest rate and real share prices.

Finally, the other option in developing an FCI is a liner weighted combination of financial variables through the factor analysis. It extracts weighted liner factor from a numbers of variables which is suppose to detect common structure and remove 'noise' created by irregular movements. Watson (1999) and Gauthier et al. (2004) use this technique as an alternative to VAR impulse and the reduced form models.

2.2.6 The use of the FCI in monetary policy

The FCI can be used in a number of different ways. Goldman and Sachs (1999) and Macroeconomic Advisers (1998) use it to predict inflation and output growth several quarters ahead and to predict the future course of monetary policy. Goodhart and Hofmann (2001, 2003) find that the FCI can be used as a leading indicator to predict inflation and output as it contains useful information about future inflation. Gauthier et al.(2004) argue that when there are shocks to the economy, changes in the FCI may provide an indication of the markets' reactions and expectations regarding future monetary policy. They further write "the FCI can be used as a synthetic measure of the financial conditions that economic agents face and thus constitutes a broad assessment of the financial stance."

More specifically, the FCI can be used in two different ways in the conduct of monetary policy – as an important informative variable or as an operational target. Under the first approach, the FCI enters in a monetary policy reaction function so that central bank not only responds to deviations of inflation from the target and to the output gap but also to the FCI. This approach can be found in Montagnoli and Napolitano (2005) who find that FCI-augmented Taylor Rule outperforms the simple Taylor rule.

The FCI can also be used as a policy rule. Goodhart and Hofmann (2001, 2003) argue that the optimal monetary policy reaction function is such that the interest rate should not only react to inflation and output gap but also to the real exchange rate, real house prices and real share price. Under this option, policymakers aim to keep FCI at a par by changing short-term interest rates in order to minimise adverse effects of asset prices to the output gap and inflation. This framework is similar to the MCI rule that has been used by the Bank of Canada, with a few other central banks, as intermediate target since early 1990s (Freedman, 1994, Duggay, 1994).

The FCI is, however, a recently developed approach to deal with a broader view of monetary policy but never been tested as an operational target or any type of policy rule by the central banks. Although it contains important information for predicting inflation and output, it has been criticised on two grounds. Firstly, it is model dependent and robust estimation including the issues of parameter inconsistency, dynamism, and non-exogeneity never been conducted properly, which limits the scope of applicability (Eika et al. 1996, Ericsson et al. 1996 and Gerlach and Smets 2000).

Secondly, Bernanke and Gertler (1999) and Gertler et al. (1999) oppose using the FCI as a policy variable. They argue that monetary policy would be more volatile if central banks use FCI as a policy variable due to uncertainty and a high volatility contained in share prices and house prices.

2.3 Financial conditions index: a theoretical formulation

In this section, we propose a theoretical framework where the FCI weights can be obtained from a macroeconomic structural model. The model consists of an open economy Philips curve, an open economy IS curve and the UIP. After formulating the structural model, we then define two types of inflation targeting framework, strict CPI inflation and domestic inflation targeting, as an objective of monetary policy. Finally, we combine each policy objective with the structural model to obtain an optimal monetary policy reaction function with appearing an FCI.

2.3.1 Structural model

We use a small scale macroeconomic model to obtain the optimal monetary policy reaction function. This model assumes an open economy where the exchange rate is assumed to be flexible.

The structural model consists of three equations, a Philips curve, an IS curve and the UIP as:

$$\pi_t = \pi_{t-1} + \lambda_1 y_{t-1} - \delta_1 (e_{t-1} - e_{t-2}) + \eta_t \tag{2.6}$$

$$y_t = -\beta\, r_{t-1} - \delta_2 e_{t-1} + \lambda_2 y_{t-1} - \theta_i z_{i,t-1} + \varepsilon_t \tag{2.7}$$

$$r_t = r_t^f \;- (E_t e_{t+1} - e_t) + \mu_t \tag{2.8}$$

Where, π_t is the CPI inflation, y_t is the output gap (i.e the difference between actual and potential output), e_t is the real effective exchange rate (REER)[7], $z_{i,}$ is the financial variable, r_t is the domestic real interest rate, r_t^f is the foreign real interest rate, and $E_t e_{t+1}$ is the expectation formed at time t for the real exchange rate at time t+1.

[7] an increase in e_t denotes an appreciation of home currency vis-à-vis foreign currencies.

η_t and ε_t are random shocks to inflation and output respectively. They are assumed to be mutually uncorrelated with zero mean and constant variances. Finally, μ_t is defined as the time varying premium. For simplicity, constants are normalized to zero and all variables except interest rate are measured in logs.

Eq. (2.6) is a standard open-economy Phillips curve as used by many authors (for instance Ball, 1998 and Guender and Matheson, 2002 amongst others). It describes that changes in current inflation depends on its own lag, the output gap, lagged changes in the real exchange rate as well as a supply shock.

Following Ball (1998), Goodhart and Hofmann (2003), we define an open economy IS curve in Eq. (2.7) where the output gap depends on lags of the real interest rate, lags of the real exchange rate, its own lag, lags of financial variables and a demand shock. Depending upon the state of the economy and the effectiveness of monetary policy, financial variables can be any combinations of equity and property prices as proposed by Goodhart and Hofmann (2003) or the long term interest rate and financial ratios as proposed by Kennedy and Riet (1995).

We introduce uncovered interest parity (UIP) in Eq. (2.8). Following Ball (1998) we believe that the UIP condition does not hold perfectly so that a time varying premium, μ_t, plays a role in the model.

2.3.2 Inflation targeting

Following Taylor (1993), a large bulk of literature assumes that policymakers aim to minimize the variability of inflation and the variability of real output from their respective targets. This type of policy setting provides a trade off between inflation and output.

We consider a special case of this framework where inflation targeting is considered to be the only objective of monetary policy (Guender and Matheson, 2002 and Ball, 1998). Further, we specify the role of the real exchange rate within the inflation targeting framework as it has twin effects on inflation. It affects directly through the import price channel and indirectly through the effects on aggregate demand (see Bernanke et al., 1999 and Ball 1999 for more discussion).

In order to address this issue in the conduct of monetary policy, we consider two types of inflation targeting frameworks, namely, strict CPI inflation targeting and domestic inflation targeting. In the former case, imported inflation is included in the measurement of the CPI, implies that the monetary authority does not consider the direct effects of the REER separately. In the latter case, however, the authority considers the domestic inflation and the import price separately.

We first derive an optimal monetary policy reaction function for the CPI inflation targeting and then consider the domestic inflation targeting. Under both frameworks, we obtain the optimal monetary policy reaction function in terms of the FCI.

2.3.2.1. Strict CPI inflation targeting framework

Following Guender (2001a, 2001b), Guender and Matheson (2002) and Ball (1998) among others, we assume that policymakers announce a strict target for CPI inflation for the two periods ahead:

$$\pi^{*} = E_t \pi_{t+2} = 0 \tag{2.9}$$

Where, π^{*} is the inflation targeted rate, $E_t \pi_{t+2}$ is the expectation formed at time t of CPI inflation at time t+2.

To construct the optimal reaction function, we update Eq. (2.6) by two periods and take conditional expectations; yields,

$$E_t \pi_{t+2} = E_t \pi_{t+1} + \lambda_1 E_t y_{t+1} - \delta_1 (E_t e_{t+1} - e_t) \tag{2.10}$$

substituting Eq. (2.10) into (2.9) and rearranging the terms results in:

$$E_t e_{t+1} - e_t = \frac{1}{\delta_1}(E_t \pi_{t+1} + \lambda_1 E_t y_{t+1}) \tag{2.11}$$

Now, replacing Eq. (2.11) into (2.8), we get:

$$\delta_1 (r_t^f - r_t) = E_t \pi_{t+1} + \lambda_1 E_t y_{t+1} + \mu_t \tag{2.12}$$

Again, updating and taking expectations in Eq. (2.6) and (2.7) results in:

$$E_t \pi_{t+1} = \pi_t + \lambda_1 y_t - \delta_1 (e_t - e_{t-1}) \tag{2.13}$$

$$E_t y_{t+1} = -\beta\, r_t - \delta_2 e_t + \lambda_2 y_t - \theta z_t \tag{2.14}$$

Substituting Eq. (2.13) and (2.14) into (2.12) and re-arranging terms with appearing r_t, e_t and z_t on left hand side, yields:

$$\varpi_1 r_t + \varpi_2 e_t + \varpi_3 z_t = \pi_t + \delta_1 e_{t-1} + \lambda_1 (1 + \lambda_2) y_t - \partial_1 f_t^f + \mu_t \tag{2.15}$$

where,

$$\varpi_1 = \lambda_1 \beta - \delta_1 \tag{2.16}$$

$$\varpi_2 = \lambda_1 \delta_2 + \delta_1 \tag{2.17}$$

$$\varpi_3 = \lambda_1 \theta \tag{2.18}$$

Eq. (2.15) is the optimal monetary policy reaction function with an FCI components (r, e, and z) on the left hand side where ϖ_i (for i=1 to3) are coefficients of the real interest rate, the real exchange rate and the financial variable respectively.

Finally, we rescale[8] ϖ_i by dividing $\lambda_1(\beta+\delta_2+\theta)$ [9], we get,

$$W_i = \frac{\varpi_i}{\lambda_1(\beta+\delta_2+\theta)} \qquad \text{(for i = 1 to 3)} \tag{2.19}$$

Where, w_i is the relative weight of asset i

As stated, our model is flexible in nature as we can add or remove any asset prices in the FCI framework depending on their relevancy to the economy. On the other hand, if we exclude asset prices from the model, i.e. when z=0, the model reduces to the MCI, which can be written as

$$\psi_1 r_t + \psi_2 e_t = \pi_t + \delta_1 e_{t-1} + \lambda_1(1+\lambda_2)y_t - \partial_1 f_t^f + \mu_t \tag{2.20}$$

where,

$$\psi_1 = \lambda_1\beta - \delta_1 \tag{2.21}$$

$$\psi_2 = \lambda_1\delta_2 + \delta_1 \tag{2.22}$$

[8] The reason for re-scaling coefficients is given in section 2.

[9] Which is the sum of the coefficients of asst prices, i.e. $\varpi_1 + \varpi_2 + \varpi_3$

$$W_i' = \frac{\psi_i}{\lambda_1(\beta+\delta_2)} \qquad \text{(for i = 1 to 2)} \tag{2.23}$$

Eq. (2.20) is an optimal reaction function with appearing an MCI on the left hand side leaving right hand side unchanged.

2.3.2.2. Domestic inflation targeting framework

In the CPI inflation targeting framework, the condition $\lambda_1\beta > \delta_1$ must be satisfied in Eq. (2.16) and (2.21) in order to get a valid interpretation of the model. Any violation produces a paradoxical result and the model becomes unstable.

This situation may arise if there is a heavy pressure of import prices on CPI. In this context, we argue that policymaker should consider the domestic inflation and the imported inflation (i.e. exchange rate) separately in order to identify this problem. Therefore, following Ball (1999) and Guender and Matheson (2002) we modify the objective function as given by Eq. (2.9) as follows:

$$\pi^* = E_t\pi_{t+2} + \delta_1(E_te_{t+1} - e_t) = 0 \tag{2.24}$$

Eq. (2.24) depicts the domestic inflation targeting framework where the term $E_t\pi_{t+2}$ is the expectation formed at time t of domestic inflation at time t+2. The parameter δ_1 is an escalating factor which measures the direct impact of expected change in the real exchange rate on inflation.

In the extreme case, when δ_1=0, there would be no difference between the CPI inflation targeting and domestic inflation targeting frameworks, indicating that there is no direct role of the change in the real exchange rate on inflation. On the other extreme, when δ_1=1, there would be a proportional relationship between the change in the real exchange rate and inflation, indicating that the inflation is overwhelmingly determined by the exchange rate. We consider δ_1 such that 0<δ_1<1.

In the process of formulating the optimal reaction function, we substitute Eq. (2.24) into (2.10), which results in:

$$E_t\pi_{t+1} + \lambda_1 E_t y_{t+1} = 0 \tag{2.25}$$

Now, inserting Eq. (2.13) and (2.14) into (2.25) and rearranging the terms we obtain the optimal monetary policy reaction function with appearing an FCI on the left hand side as:

$$\omega_1 r_t + \omega_2 e_t + \omega_3 z_t = \pi_t + \delta_1 e_{t-1} + \lambda_1(1+\lambda_2)y_t \tag{2.26}$$

where $\omega_1 = \lambda_1\beta$ (2.27)

$$\omega_2 = \lambda_1\delta_2 + \delta_1 \tag{2.28}$$

$$\omega_3 = \lambda_1 \theta \qquad (2.29)$$

And, relative weights can be calculated as:

$$W_i = \frac{\varpi_i}{\lambda_1(\beta + \delta_2 + \theta) + \delta_1} \qquad \text{(for i = 1 to 3)} \qquad (2.30)$$

As in the previous case, we can now obtain the optimal monetary reaction function with appearing an MCI on the left hand side by excluding financial variable, z, from Eq. (2.26). In doing so, yields;

$$\nu_1 r_t + \nu_2 e_t = \pi_t + \delta_1 e_{t-1} + \lambda_1 (1 + \lambda_2) y_t \qquad (2.31)$$

where, $\nu_1 = \lambda_1 \beta_1$ (2.32)

$$\nu_2 = \lambda_1 \delta_2 + \delta_1 \qquad (2.33)$$

And, weights for MCI appears as

$$W'_i = \frac{\nu_i}{\lambda_1(\beta + \delta_2) + \delta_1} \qquad \text{(for i = 1 to 2)} \qquad (2.34)$$

Table 2.2 summarises the measurement of the FCI and the MCI weights. The Panel A gives the weighting structure for the strict CPI targeting framework as abstracted from Eq. (2.15) and (2.20) respectively. Similarly, the Panel B summarises the FCI and the MCI weights for the domestic inflation targeting framework as obtained from Eq.

(2.26) and (2.31). The panel C is the classical FCI and MCI weights abstracted from the existing literature.

Table 2.2: Comparison of FCI/MCIs weights

Type/Weights on	Real interest rate	REER	Financial Variable
	Panel A: CPI inflation targeting framework		
FCI	$\frac{\lambda_1\beta-\delta_1}{\lambda_1(\beta+\delta_2+\theta)}$	$\frac{\lambda_1\delta_2+\delta_1}{\lambda_1(\beta+\delta_2+\theta)}$	$\frac{\lambda_1\theta}{\lambda_1(\beta+\delta_2+\theta)}$
MCI	$\frac{\lambda_1\beta-\delta_1}{\lambda_1(\beta+\delta_2)}$	$\frac{\lambda_1\delta_2+\delta_1}{\lambda_1(\beta+\delta_2)}$	-
	Panel B: Domestic inflation targeting framework		
FCI	$\frac{\lambda_1\beta}{\lambda_1(\beta+\delta_2+\theta)+\delta_1}$	$\frac{\lambda_1\delta_2+\delta_1}{\lambda_1(\beta+\delta_2+\theta)+\delta_1}$	$\frac{\lambda_1\theta}{\lambda_1(\beta+\delta_2+\theta)+\delta_1}$
MCI	$\frac{\lambda_1\beta_1}{\lambda_1(\beta+\delta_2)+\delta_1}$	$\frac{\lambda_1\delta_2+\delta_1}{\lambda_1(\beta+\delta_2)+\delta_1}$	-
	Panel C: Conventional measurement		
FCI	$\frac{\beta}{\beta+\delta_2+\theta}$	$\frac{\delta_2}{\beta+\delta_2+\theta}$	$\frac{\theta}{\beta+\delta_2+\theta}$
MCI	$\frac{\beta}{\beta+\delta_2}$	$\frac{\delta_2}{\beta+\delta_2}$	-

Note: Panel A and panel B are based on our own formulation as given in section 2.3 while panel C is abstracted from the literature. The FCI weights given in Panel C can be found in Lack (2003), Mayes and Viren (2001), Goodhart and Hofmann (2001). Similarly, the source of the conventional MCI weights are Korhonen (2002), Gerlach and Smets (2000), Lin (1999), Siklos (2000), Dennis (1997), Duguay (1994), Kesriyeli(1999,) Gottschalk (2001), Nadal et al. (1996).

Comparing panel A and B with panel C, we can observe that our indices are improvement over the existing literatures for two reasons. Firstly, in our framework, the relative weights of asset prices are obtained from a structural model which combines both the IS and the Philips curve as compared to the IS curve alone on the existing literature.

Secondly, our FCI weights take an account of both the direct and indirect effects of the changes in the real exchange rates where the direct effect transmits through δ_1 and indirect effect through δ_2. The existing literature, on the other hand, excludes δ_1 in the FCI weights.

2.4 Empirical estimates of the financial conditions index

2.4.1 Data generating process and unit root test

We consider two open economies, the UK and the USA, for our empirical analysis. As monthly GDP series is not available, we use quarterly time series data for both countries. The sample period covers from 1979Q1 to 2003Q4. Following Goodhart (2001) we use the real interest rate, r, the real effective exchange rate, e, real house prices, h, and real share prices, s, in the construction of FCIs. We use logs of all variables except for the interest rate[10].

We use real GDP as the measure of output and employ the Hodrick-Prescott filter with smoothing parameter set at 1600 to obtain potential output. The output gap, y, is then measured by subtracting potential output from the actual. The real interest rate, r, is obtained by subtracting inflation, π, from the nominal interest rate , R. π is calculated as the percentage change in the consumer price index over the same quarter of the previous year. We use the real effective exchange rate (REER) as a measure of the exchange rate, where an increase indicates appreciation of home currency vis-à-vis foreign currencies. The sources and definitions of variables are given in Appendix 2.1.

We next run the augmented Dickey-Fuller (Dickey and Fuller, 1979) and Phillip and Perron (1988) tests to test the stationary of our variables (See Appendix 2.2 for the detailed methodology). Both tests the null hypothesis of a unit root but the procedure is a little different. While the former test makes a parametric correction for higher-order correlation by assuming that the series follows an auto-regressive process with order ar(p) and adjusts the test methodology by adding lags of independent variables,

[10] However, the distribution of the US and the UK interest rate are asymmetric around their mean because the skewness for the US and UK interest rates are found to be 0.90 and 0.26 respectively. On the other hand, the US interest rate is peaked whereas the UK interest rate is flat relative to the normal as the kurtosis of the US and UK interest rates are recorded to be 3.74 and 1.88 respectively.

the PP method tests the unit root through a non-parametric correction procedure (Banerjee et al., 1993).

Table 2.3: ADF test (1979Q1 to 2003Q4)

Variables	y_t	$\pi_t - \pi^T$	R_t	e_t	s_t	h_t
Panel A: UK						
Level	-1.01	-3.52*	-2.91**	-2.17	-0.97	-2.38
First Difference	-4.08*			-5.21*	-3.58*	-4.12*
Deviations from the equilibrium#	-3.96*			-5.17*	-4.98*	-4.68*
Panel B: USA						
Level	-0.14	-3.88*	-3.01**	-1.13	-0.14	-0.12
First Difference	-3.18*			-3.98*	-4.42*	-3.01**
Deviations from the equilibrium#	-3.88*			-5.61*	-3.77*	-3.53*

Note: 1. Mackinnon critical values for the rejection of the null hypothesis at 1%, 5% and 10% are -3.49, -2.89 and -2.59 respectively.

2. # Equilibrium values are obtained using the Hodrick-Prescott (1977) filter.

3. Data source and definition of variables are given in Appendix 2.1

*4. * and ** indicate significant at 1% and 5% respectively.*

Table 2.3 shows the test results. We find similar results from both the ADF and PP tests so we only report the ADF test to save space. We find inflation, output gap and the real interest rate to be I(0) while house price, share price and the real exchange rate indices to be I(1) process.

2.4.2 Estimation and interpretation

In this section, we first estimate the structural model given by section 2.3.1 and then compute the FCI and MCI using the formulae given in Table 2.2.

Table 2.4 reports the OLS estimates of the open economy Philips curve, that is Eq. (2.6), for the UK and the USA. The lag length is chosen using a general to specific approach starting from 9 lags, but the best estimate is obtained when using up to five lags of the dependent variable for both countries.

Both estimates are well specified. The DW statistics reject the null of a unit root whilst Godfrey's (1988) Lagrange Multiplier (LM) test suggests that there is no autocorrelation in the residuals. Moreover, no functional form misspecification is detected by the Ramsey's (1969) RESET test and the non-normality of the estimate is rejected by Jarque-Bera's (1980) test. Evidence of homoscadesticiy is clearly established. Also, no signal of auto regressive conditional heteroscadesticity appears both from the first order and up to fourth order condition. Finally, our estimates pass CUSUM and CUSUMQ tests, indicating that the estimates are stable.

Our results are in line with the existing empirical findings for both countries as inflation has a positive relationship with the output gap and an inverse relationship with the REER. The effect of the real exchange rate on inflation in UK is higher than that of the USA. The change in the oil price is also found to be significant at 5% for both countries.

Table 2.4: Philips curve estimates

[Model: $\pi_t = \pi_{t-1} + \lambda_1 y_{t-1} + \delta_1 \Delta e_{t-1} + \eta_t$]

Estimated Parameters \ Country (lag length of the dependent variable)	UK (1-5)	USA (1-5)
λ_1	0.250 (0.039)*	0.171 (0.056)*
δ_1	-0.027 (0.009)*	-0.013 (0.005)**
ΔOP	0.015 (0.008)**	0.017 (0.007)**
Diagnostic statistics/tests		
Adjusted R^2	0.94	0.95
Durbin-Watson statistics	1.74	1.72
Standard error of regression	0.43	0.56
Jarque-Bera statistics for normality test	3.01 [0.18]	4.29 [0.12]
Breusch-Godfrey serial correlation LM(1)	0.98 [0.32]	2.15 [0.14]
Breusch-Godfrey serial correlation LM(4)	1.26 [0.29]	1.47 [0.23]
ARCH 1	0.04 [0.83]	1.56 [0.21]
ARCH 4	1.72 [0.15]	2.01 [0.11]
White's heteroskedasticity test	1.73 [0.13]	2.09 [0.06]
Ramsey's RESET test	1.49 [0.33]	1.03 [0.30]
Chow's breakpoint test	1.16 [0.34]	2.12 [0.10]

Note:

(a) ΔOP is the coefficient of the change in the oil price. Notice that this variable is not included in (2.5) to make the model simpler but included in the empirical estimations to get more robust results (see Goodhart and Hofmann, 2003 for the similar experiment).

(b) *Sample period for UK and USA are 1980Q1-2003Q3 and 1979Q3-2003Q4 respectively.*

(c) *Constant and lags of dependent are also included in the estimates but is not reported to save space, is available on request.*

(d) *() is the standard error and [.] is the probability of the test statistics.*

(e) **, ** and *** indicate significant at 1%, 5% and 10% respectively.*

(f) *Chow's breakpoint is 1992.Q4 and 1987.Q3 for the UK and USA respectively.*

Next, we estimate the IS curve for the UK and the USA, that is Eq. (2.7). Table 2.5 reports the empirical estimates. We find that the real interest rate and the REER have a negative impact while real house prices and real share prices have a positive impact on the output gap. The size of the estimated coefficients show that the real interest rate has a greater impact on the output gap in USA followed by real house prices, share prices and the REER. However, the REER and real house prices have a similar impact on the output gap in UK after the real interest rate.

Using the methodology given in Table 2.2 and the estimated coefficients from Tables 2.4 and 2.5, we now obtain the weights on real interest rates, REER, real house prices and real share prices for the construction of FCI. Notice that the financial variable, z, as discussed in our theoretical model comprises real house prices and real share prices in our empirical analysis. Therefore, we replace θ by θ_1 and θ_2 in Table 2.2 in order to get separate weights of these variables.

Table 2.5: IS curve estimates

[Model: $y_t = \lambda_2 y_{t-1} + \beta\, r_{t-1} + \delta_2 e_{t-1} + \theta_1 hp_{t-1} + \theta_2 sp_{t-1} + \varepsilon_t$]

Estimated Parameters \Country (lag length of the dependent variable)	UK (1-3)	USA (1-5)
β	-0.140 (0.058)**	-0.105 (0.022)*
δ_2	-0.027 (0.013)**	-0.016 (0.009)***
θ_1	0.027 (0.005)*	0.081 (0.025)*
θ_2	0.012 (0.005)**	0.063 (0.016)*
Diagnostic statistics/tests		
Adjusted R^2	0.88	0.86
Durbin-Watson statistics	2.11	1.89
Standard error of regression	0.39	0.50
Jarque-Bera normality test	3.66 [0.16]	2.32 [0.31]
Breusch-Godfrey LM(1)	2.56 [0.11]	0.24 [0.62]
Breusch-Godfrey LM(3)	0.95 [0.43]	1.20 [0.31]
ARCH 1	0.09 [0.76]	3.10 [0.13]
ARCH 3	0.08 [0.98]	1.47 [0.21]
White's heteroskedasticity	0.62 [0.78]	1.51 [0.10]
Ramsey's RESET test	0.41 [0.51]	0.13 [0.71]
Chow's breakpoint test	1.16 [0.33]	1.24 [0.27]

Note: (a) Sample period for UK and USA are 1980Q1-2003Q3 and 1979Q3-2003Q4 respectively.

(b) Constant and lags of dependent are also included in the estimates but is not reported to save space, is available on request.

(c) (.) is the standard error and [.] is the probability of the test statistics.

*(d) *, ** and *** indicate significant at 1%, 5% and 10% respectively.*

(e) Chow's breakpoint is 1992.Q4 and 1987.Q3 for the UK and USA respectively.

Table 2.6 gives the weights of variables under various specifications. The second column reports the weighting structure for the FCI when the authority targets CPI inflation while the third column gives the FCI weights when the policy objective is domestic inflation targeting. Finally, the last column is based on the conventional methodology.

The FCI weights generated from conventional methodology is comparable with the literature for both countries. This justifies our estimating procedure and quality of data set (see Goodhart, 2001, 2003). This framework reveals that the real interest rate is the most influential variable followed by the REER, real house prices and real share prices.

Under the CPI inflation targeting framework, on the other hand, the REER carries overwhelming share followed by the real interest rate, real house prices and real share prices in UK. In the case of USA, however, the real interest rate takes the smallest share after the REER, real house prices and real share prices. The stability condition, $\lambda_1 \beta > \delta_1$, is not violated in either countries.

The FCI weights for the domestic inflation targeting framework are close to the conventional measurement for both countries where the real interest rate takes the highest share. The REER, real house prices and real share prices come at second, third and fourth ranking respectively.

Table 2.6: FCI weights

Variables	CPI inflation targeting framework (FCI_1)	Domestic inflation targeting framework (FCI_2)	Conventional measurement (FCI_3)
Panel A: UK			
Real interest rate	0.154	0.443	0.673
REER	0.659	0.434	0.139
Real house prices	0.130	0.085	0.130
Real share prices	0.058	0.038	0.058
Panel B: USA			
Real interest rate	0.108	0.307	0.395
REER	0.348	0.270	0.060
Real house prices	0.306	0.238	0.306
Real share prices	0.238	0.185	0.238

Note: See Table 2.2 for the methodology and Table 2.4 and 2.5 for the estimated coefficients.

Although the focus of this chapter is to estimate the FCI, we also compute the MCI weights for the comparison purpose (Appendix 2.2). Not surprisingly, we get the same message regarding the relative importance of the real interest rate and the REER in the conduct of monetary policy for both countries (Appendix 2.3 and 2.4)

Figure 2.1 and 2.2 plots the FCIs for the UK and the USA. The indices are based on the computed weights as shown in Table 2.6 and historical time series beginning from

1979Q1 to 2003Q4. The reference period is assumed to be 2000Q1 for all specifications and countries. We emerge the following conclusions from these figures.

First, the UK and USA tightened monetary policy during the 1980s as we find that both FCI_2 and FIC_3 exceeded the par level. One of the reasons for tightening monetary policy could be the response to a high level of inflation resulted from the oil price shocks and relatively a higher level of budget deficits during this period. Not surprisingly, the FCI_1, however, shows a contradict result for this period which is less likely to be justified. It is because, as discussed earlier, the FCI_1 does not provide a realistic policy stance when the foreign shocks have a greater impact on Philips curve. This has been a case for the USA during 1980s (Goldman Sachs, 1999).

Second, policy may have responded to the Asian financial crises in 1997 as the FCI exceeded the par level. Third, monetary policy has been more accommodative since the beginning of this century as all indices are below the par level. Fourth, FCIs and MCIs are stable for the ongoing inflation targeting period (post Oct 1992) in UK and the Greenspan period in the USA, implies that monetary policy has been successful to stabilize the inflation.

Figure 2.1
UK: Financial Conditions Indices

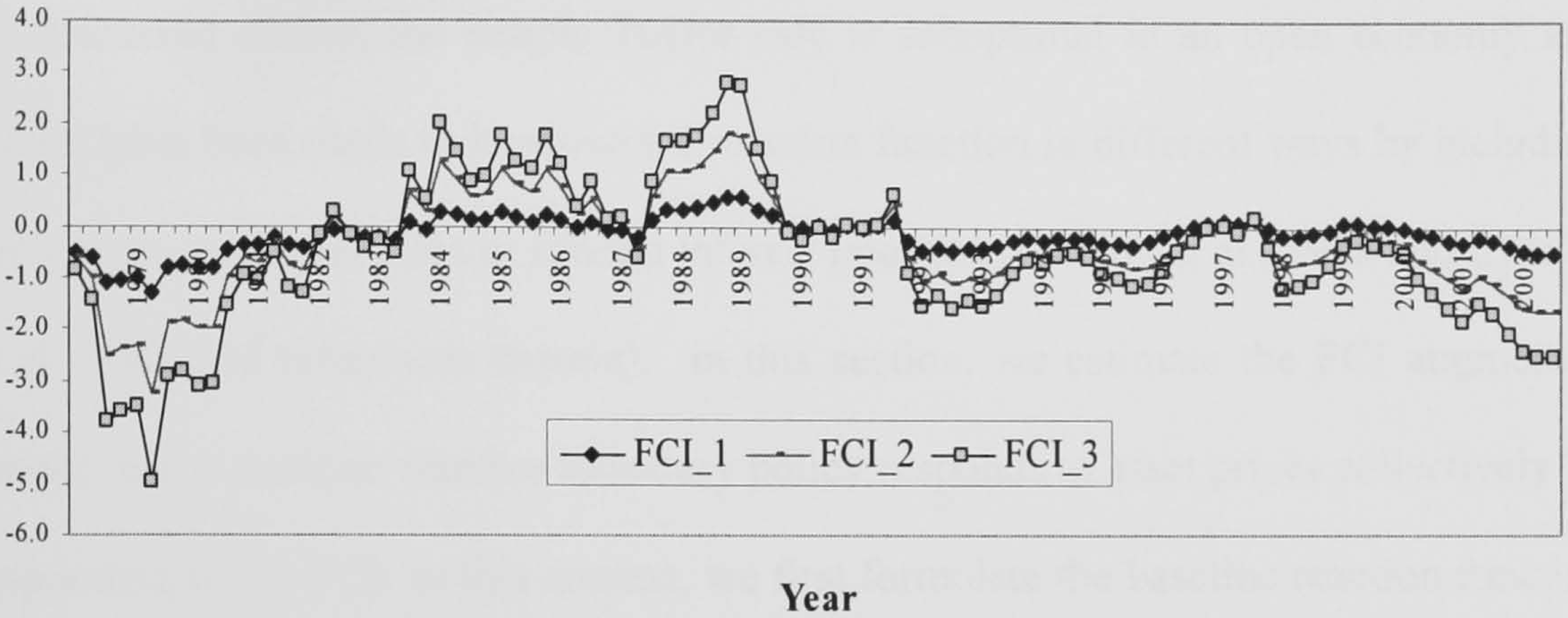
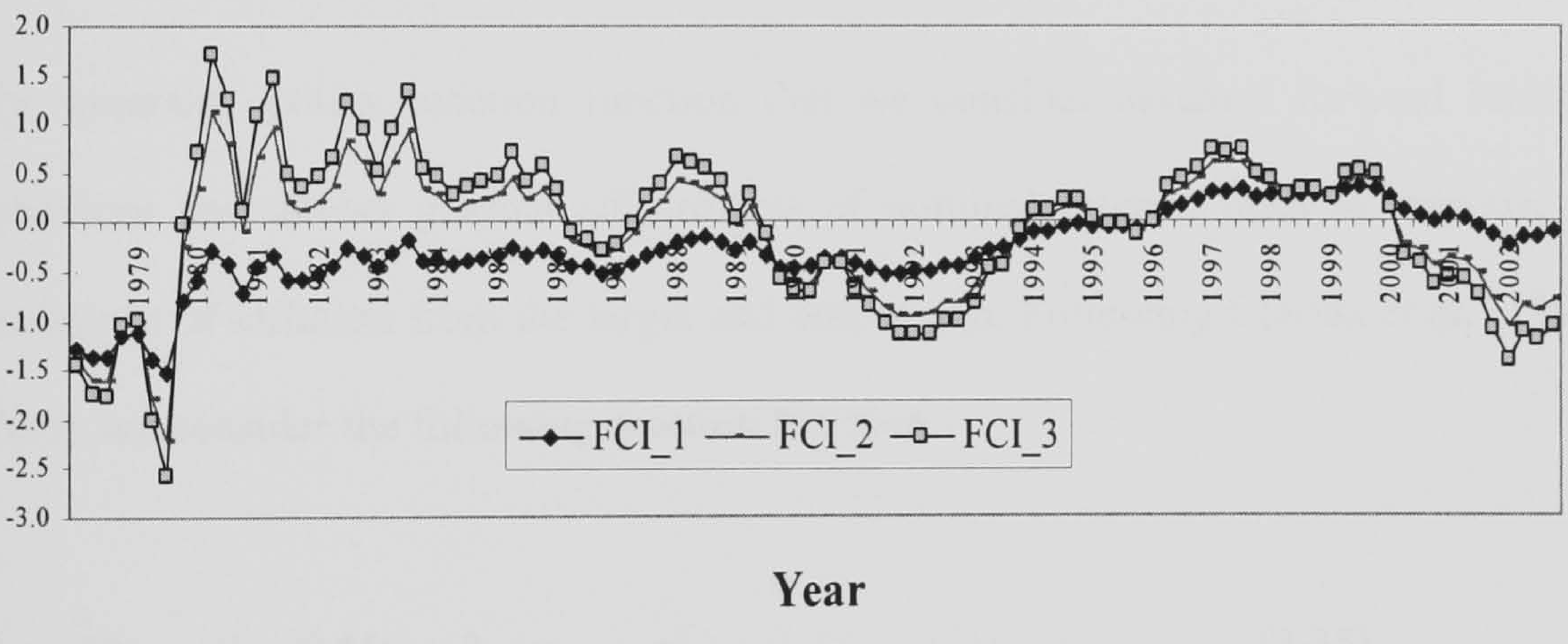


Figure 2.2
USA: Financial Conditions Indices



2.5 Monetary policy reaction function and the use of FCI

As discussed earlier, the simple Taylor rule is suboptimal in an open economy and efforts have been made to improve the reaction function in different ways by including asst prices, exchange rates or foreign interest rates (see Clarida et al., 1998 and Chadha et al. 2004 and references therein). In this section, we estimate the FCI augmented Taylor rule to analyse whether monetary policy responds to asset prices collectively by responding to the FCI. In this context, we first formulate the baseline reaction function and then discuss the FCI augmented reaction function.

2.5.1 Basic Taylor rule

The monetary policy reaction function that we consider assumes forward looking behaviour and allows gradual adjustments of nominal interest rates in response to deviations of inflation from the target and output gap. Following Clarida et al. (1998, 2000), we consider the following reaction function.

$$R_t = \partial R_{t-1} + (1-\partial) * [C + \partial_\pi (\pi_{t+n} - \pi^T) + \partial_y (y_t - y_t^*)] + v_t \qquad (2.35)$$

The set of orthogonality conditions implied by the above model is:

$$\mathrm{E}_t \{R_t - \partial R_{t-1} - (1-\partial) * [C + \partial_\pi (\pi_{t+n} - \pi^T) + \partial_y (y_t - y_t^*)]\} | \Omega_t = 0 \qquad (2.36)$$

Where, R_t is the short term nominal interest rate, π_{t+n} is inflation at time t+n, π^T is targeted level of inflation, y_t is actual GDP. y_t^* is HP trended GDP (calculated by passing real GDP through the Hodrick Prescott filter with the smoothness parameter set at 1600). v_t is white nose. ∂_π and ∂_y are parameters assigned to inflation and output respectively. ∂ is the degree of interest rate smoothening and assumed to be $0<\partial<1$[11]. Ω_t is the information set available for policymakers while setting R_t.

This framework allows a gradual adjustment of the interest rate towards its targeted level and is found to be superior for the policy purpose for at least two reasons. First, Goodfriend (1991, 1997) argues that the interest rate inertia allows the central bank to communicate its policy more clearly so that financial instability due arising from uncertainty could be minimized.

[11] In the extreme cases, when $\partial=0$ the Taylor rule does not allow to smooth changes in the interest rate, indicating that the central bank has a perfect control over short term interest rates. In this case the model describes a situation that policymakers adjust short term interest rates to the desired level as and when required. The recent literature strongly oppose this case and argues that policy inertia operates in practice (Clarida et al., 1998, Castelnuovo, 2003, Svensson, 1997 and Orphanides (2002). On the other extreme when $\partial=1$ policy does not respond to inflation and output but follows the autoregressive trend which is again not true in practice.

Second, Goodhart (1999), Woodford (2001), Orphanides (2001), Judd and Rudebusch (1998) and Clarida et. al. (1988), among others, find that this type of framework makes future path of policy change more predictable and helps to increase policy effectiveness. More specifically, as pointed out by Goodhart (1999), a gradual adjustment policy framework avoids a frequent policy reversal which is very important in the conduct of monetary policy because a frequent policy reversal reflects an incapability of policymakers.

2.5.2 Augmented Taylor rule

Although forward looking monetary policy inertia as discussed above is found to be superior over conventional Taylor Rule, it has some limitations. First, as pointed out by Kerr and King (1995), Bernanke and Woodford (1997) and Clarida et al. (1998), the policy feedback rule itself may be a source of instability if the coefficient of deviations of inflation from the target (∂_{π}) is below unity. Second, even if the coefficient is valid, the policy feedback rule may not capture the market phenomenon due to the exclusion of other important assets prices like share prices and house prices. Recent contributions show that share price and assets price help to predict interest rate more accurately (eg. Montagnoli and Napolitano, 2005).

More specifically, Kristen (2004) argues that the Taylor rule is less important for policy purpose if financial variables are excluded from the reaction function. He expands the Taylor rule by including financial market conditions as proxied by difference between the short term Treasury bill rate and the long term risky bond and finds robust estimation for the US (see also Mehra[12], 1999). Gerlach and Schnabel (2000) and Clarida et al. (1998) modify the forward looking Taylor rule by including monetary growth and exchange rate separately and find that these variables contains an important source in the interest rate setting. They, however, recognized the role of other assets prices in the feed back rule but do not address them.

Smets (1997), on the other hand, includes the nominal trade-weighed exchange rate, a ten-year nominal bond yield and a broad stock market index in the augmented Taylor rule for Canada and Australia but does not give any role to house prices. Goodhart and Hofmann (2001, 2003) find that the FCI contains useful information in the prediction of the output and inflation.

In this context, we propose an FCI augmented Taylor rule in which case policy responds to the FCI as an alternative to each asset prices separately. The augmented reaction function we consider takes the following form:

$$R_t = \partial R_{t-1} + (1-\partial) * [C + \partial_\pi (\pi_{t+1} - \pi^T) + \partial_y (y_t - y_t^*) + \partial_{A,i} FCI_{t,i}] + v_t \qquad (2.37)$$

and the orthogonality conditions is given by:

[12] He use only long term bond rate in his augmented Taylor rule for US.

$$E_t\{R_t - \partial R_{t-1} - (1-\partial)*[C + \partial_\pi(\pi_{t+n} - \pi^T) + \partial_y(y_t - y_t^*) - \partial_{A,i} FCI_{t,i}]\}|\Omega_t = 0 \quad (2.38)$$

Where, subscript i (for i = 1 to 3) indicates three scenarios of FCIs as defined in the previous section and $\partial_{A,i}$ are corresponding parameters to be estimated.

2.5.3 Estimation procedure

We first estimate the basic Taylor rule as given by Eq. (2.35) and then estimate the augmented model as given by Eq. (2.37) using Generalised Method of Moments (GMM) for the UK and the USA. The instruments, Ω, are a constant and up to five lags of the nominal short-term interest rate, inflation, output gap and FCIs. Since the number of instruments are greater than parameters to be estimated, we test for the over identifying restrictions by using Hansen (1982) j-statistics for all estimations[13]. In this context, the test of the over identifying restriction is very important. A rejection of the null hypothesis that the over identifying restriction is satisfied implies that instruments are not orthogonal to the error term. This suggests that the model is mis-specified.

We use quarterly data over the period 1979Q2 to 2003Q4 for UK when controlling inflation became a clear policy objective and 1979Q3 to 2003Q4 for USA when Volcker, the then Governor of Fed, signalled his intention to reign in inflation (Clarida et al., 1998). A full sample estimate is less useful because policy has changed

[13] Interpretation of over identifying restriction can be found in Clarida et al. (1998)

significantly during this period. For instance, UK has adopted inflation targeting since October 1992. On the other hand, Fed does not target inflation explicitly but it is argued that it has targeting implicitly in a way of explicit targeting since the beginning of Greenspan tenure (1987Q3 – 2005Q4). In this context, we split the full sample into two periods taking 1992Q4 and 1987Q3 as a reference period for the UK and the USA respectively.

2.5.4 Empirical findings

Table 2.7 reports GMM estimates of the baseline reaction function, Eq. (2.35), for UK. The Panel A reports estimates for the pre inflation targeting period while Panel B reports the estimates for the inflation targeting era. Both estimates are quite consistent with the existing literature as we find policy gives a more weight to inflation and less to the output gap in the ongoing inflation targeting regime (since 1992) compared to pre-inflation targeting era (Martin and Milas, 2004).

The estimates of the benchmark model indicate that the nominal interest rate increases by 1.187 percentage point in response to a 1 percentage point excess of inflation over the targeted rate in post 1992 compare to as low as 0.35 percentage point increase in the previous era. Consequently, the coefficient of output gap found to be as low as 0.50 in the inflation targeting period compare to 1.46 in the pre inflation targeting period. These results support the exiting empirical literature that the Bank of England has been more aggressive to control inflation since late 1992 compared to the previous era (see also Clarida et al., 1998).

Table 2.7: UK Taylor rule: GMM estimates

[Model: $R_t = \partial R_{t-1} + (1-\partial)*[C + \partial_\pi(\pi_{t+1} - \pi^T) + \partial_y(y_t - y_t^*) + \partial_A FCI_t] + v_t$]

Estimated Parameters	∂	C	∂_π	∂_y	∂_A	J-P	S.E N
Panel A: Pre Inflation Targeting Period (1979Q2-1992Q3)							
Benchmark Model	0.708 (0.060)*	2.584 (0.957)*	0.353 (0.171)*	1.459 (0.548)*	-	0.17	0.99 0.01
Adding: FCI_1	0.593 (0.064)*	3.296 (0.856)*	0.496 (0.172)*	0.838 (0.293)*	0.349 (0.025)*	0.14	0.85 0.17
FCI_2	0.628 (0.053)*	2.986 (0.867)*	0.503 (0.215)*	0.849 (0.333)*	1.140 (0.323)*	0.13	0.86 0.16
FCI_3	0.639 (0.062)*	2.887 (0.870)*	0.501 (0.194)*	0.867 (0.291)*	0.751 0.277)*	0.12	0.86 0.15
Panel B: Inflation Targeting Period (1992Q4-2003Q3)							
Benchmark Model	0.426 (0.141)*	3.559 (0.996)*	1.187 (0.331)*	0.500 (0.122)*	-	0.08	0.63 0.08
Adding: FCI_1	0.398 (0.143)*	2.887 (0.984)*	1.276 (0.199)*	0.435 (0.166)*	0.231 (0.017)*	0.20	0.49 0.10
FCI_2	0.386 (0.133)*	3.583 (0.955)*	1.595 (0.261)*	0.564 (0.195)*	0.656 (0.163)*	0.15	0.61 0.09
FCI_3	0.399 (0.120)*	3.461 (1.051)*	1.433 (0.233)*	0.584 (0.216)*	0.250 (0.033)*	0.13	0.63 0.07

Note:

1. *HAC standard errors are employed in the estimates.*

2. *Instruments used are a constant, 2 to 5 lags of the dependent variable, and 1 to 5 lags of inflation, output gap and FCIs. The interest rate, deviations of inflation from the target and the output gap are considered to be endogenous variables.*
3. *Numbers in parentheses are the standard errors of the estimates, N is the probability value of the normality test, J-P denotes the test statistics for over identified restrictions.*
4. *Figures in parenthesis are standard error and *, ** and *** indicate level of significance at 1%, 5% and 10% respectively.*

We, next, estimate augmented models (Eq. 2.37) by including FCI_1, FCI_2 and FCI_3 alternatively for UK. As reported in Table 2.7, we find a positive sign of the FCI coefficients for all specifications. The estimated FCI parameters ranged from 0.23 to 1.14 and are found to be significant at 1%. It implies that monetary policy in UK responds to asset prices collectively by responding to the FCI. Interestingly, the policy response to inflation is found to be stronger when the FCI is included in the reaction function, indicating that any deviation in financial conditions from fundamental may also create a threat to inflation. We also find that that the interest rate is more responsive to asset prices (i.e. the FCI) if the policy targets domestic inflation.

We, then, estimate the benchmark model for the USA. As shown in Table 2.8, the Panel A reports the estimates for Greenspan period while Panel B provides a full sample estimate. Interestingly, we find that the Fed has been more aggressive to control inflation during the Greenspan period as we find that the coefficient of deviations of inflation from the target is higher than the coefficient of the output gap. However, a weak evidence of orthogonality is alarmed in the benchmark estimate.

Table 2.8: US Taylor rule: GMM estimates

[Model: $R_t = \partial R_{t-1} + (1-\partial) * [C + \partial_\pi(\pi_{t+1} - \pi^T) + \partial_y(y_t - y_t^*) + \partial_A FCI_t] + \nu_t$]

Estimated Parameters	∂	C	∂_π	∂_y	∂_A	J-P	S.E N
Panel A: Greenspan period (1987.Q3-2003Q4)							
Benchmark Model	0.847 (0.134)*	1.196 (0.497)*	2.806 (0.551)*	1.466 (0.521)*	-	0.06	0.98 0.53
Adding: FCI_1	0.793 (0.046)*	1.368 (0.327)*	2.165 (0.781)*	1.268 (0.482)*	0.770 (0.256)*	0.39	0.50 0.23
FCI_2	0.746 (0.055)*	2.087 (0.421)*	2.574 (0.921)*	1.035 (0.425)*	0.763 (0.212)*	0.38	0.51 0.24
FCI_3	0.730 (0.064)*	2.187 (0.320)*	2.489 (0.911)*	0.914 (0.335)*	0.650 (0.184)*	0.36	0.48 0.19
Panel B: Greenspan and Volcker period (1979Q3-2003Q4)							
Benchmark Model	0.918 (0.122)*	1.290 (0.452)*	2.056 (0.381)*	2.063 (0.862)*	-	0.07	1.12 0.13
Adding: FCI_1	0.913 (0.224)*	1.819 (0.462)*	2.206 (0.425)*	1.495 (0.490)*	0.546 (0.102)*	0.27	0.73 0.17
FCI_2	0.896 (0.110)*	1.983 (0.335)*	2.278 (0.491)*	1.327 (0.282)*	0.622 (0.242)*	0.26	0.82 0.11
FCI_3	0.880 (0.123)*	1.632 (0.343)*	2.848 (0.691)*	1.601 (0.582)*	0.861 (0.324)*	0.29	0.81 0.12

Note: refer Table 2.7 for footnotes.

The problem of misspecification could be solved using the second order partial adjustment reaction function as given by Clarida et al. (1998) or using nonlinear specifications (see Dolado et al., 2002). But we argue that the misspecification in the benchmark specification is due to the omitted variable as our FCI augmented reaction functions are robust. This implies that the FCI contains important information to predict interest rate. The effect of the FCI is even higher in US than the UK as the estimated parameter ranged from 0.16 to 0.92 in US compared to a range of 0.26 to 0.42 in UK.

An effort was made to estimate the reaction function using up to 4^{th} lags of FCIs but found similar estimates. Similarly, we also tested forward, backward and contemporariness specifications of inflation and the output gap but the forward looking specifications as given by Eq. (2.35) and (2.37) outperformed to other specifications.

To sum up, our empirical evidence from the UK and the US reveals that FCI augmented reaction functions outperform the benchmark model in a number of ways. First, the standard error is sharply reduced in all augmented models compared to the benchmark estimate. Second, weak evidence of normality is detected in the benchmark model for the US but there was no sign of misspecification in the FCI augmented model. Third, we support the findings of Kristen (2004) that a high degree of smoothing parameter is due to unobserved variable. It is because smoothing coefficient is decreases sharply in our FCI augmented reaction function compared to the benchmark estimate[14].

2.6 Concluding remarks

A large bulk of literature argues that monetary policy should respond to asset prices as these variables contain important information for predicting inflation and the output gap (Goodhart, 2001). Although the issue of how and to what extent should monetary policy respond to asset prices is debatable, there is an argument that policy may respond to them collectively by responding to the FCI (Goodhart and Hofmann, 2001).

In this chapter, we address this issue extensively on both theoretical and empirical grounds. By contrast of using the IS curve alone in the conventional literature, we employ a macroeconomic structural model, which combines both the demand and supply side of the economy, to obtain the FCI. We explore two alternative FCI models, one for CPI inflation and another for domestic inflation targeting frameworks respectively. Although both of them are obtained from a macroeconomic structural model, the main difference between them is the treatment of the real exchange rate.

[14] There is a debate whether a high degree of smoothing parameter is policy inertia or the effect of unobserved variable. Rudebusch (2002) argues that smoothing can arise spuriously if variables are excluded incorrectly. Kristen (1999) finds that policy inertia with a high degree of smoothing is less important for the policy purpose. He suggests that smoothing coefficient could be reduced by the inclusion of financial variable in the reaction function.

The CPI model assumes that the real exchange rate has a direct impact on inflation via import prices and indirect effects via pressure on the aggregate demand while the latter case considers the indirect impact alone.

On the empirical side, we construct FCIs for the UK and the USA using our new as well as conventional methodologies. We, then, test the usefulness of indices by estimating the FCI augmented Taylor rule. The empirical results overwhelmingly suggest that the FCI contains important information in the conduct of monetary policy. Moreover, monetary authority can respond to asset prices by responding to the FCI as we find that the FCI augmented Taylor rules outperform the simple rule in both countries irrespective to the type of FCIs and sub-sample periods.

Chapter 3

Modelling UK Monetary Policy: A Nonlinear Perspective[15]

3.1 Introduction

Although a growing number of central banks around the globe have started inflation targeting since the early 1990s and the short-term nominal interest rate was considered to be the only effective instrument, the analytical framework of monetary policy was largely unclear until the seminal work of John Taylor (Taylor, 1993). He explored a simple linear monetary policy reaction function, in which policymakers set the interest rate in response to deviations of inflation from the target and the output gap.

[15] I am grateful to Professor Costas Milas, Keele University, UK, for his helpful comments on the earlier version of this chapter.

More recent work has extended the Taylor rule. The work can be classified into three broad groups. First, Clarida et al. (1998, 2000), among others, explore a 'smoothing reaction function' which allows a gradual adjustment in the interest rate towards equilibrium, an alternative to the 'immediate reactive' type of reaction function. This framework of monetary policy is assumed to be more transparent and predictable than the conventional Taylor rule (See also Goodfriend, 1991; Woodford, 2001; Orphanides, 1998, Judd and Rudebusch, 1998).

Second, Gerlach (2004), Mehra (1999), Clarida et al. (1998), Smets (1997), Chadha et al. (2004), among others, argue that policymakers not only respond to deviations of inflation from the target and the output gap but also to the foreign interest rates and the real exchange rate. Moreover, Goodhart and Hofmann (2000) and Goodhart (2001) argue that policy responds to property and equity prices together with inflation and the output gap.

Third, a number of recent studies argue that the monetary policy is nonlinear and the policy response is asymmetric. This is due to either a nonlinear loss function (Clark et al., 1997 and Mayes and Viren, 2001) and/or the existence of nonlinearities in the economic structure (see Schaling, 1999, Dolado et al., 2000, 2003, 2004, Stiglitz, 1997, Martin and Milas 2004).

In this backdrop, this chapter models the UK monetary policy for the post-1992 period, the explicit inflation-targeting regime. The motivation of this chapter is two-fold. First, although a number of recent studies have argued that UK monetary policy is nonlinear, this conclusion is based on a narrow framework, the Taylor rule, which does not account for asset prices or open economy effects. We argue that detection of the nonlinearity may be due to misspecification of the Taylor rule. Second, expanded reaction functions have also been explored in the literature but they do not attempt to analyze nonlinear and asymmetric aspects of monetary policy (for instance see Gerlach, 2004; Clarida et al., 1998; and Smets, 1997).

This chapter combines these two aspects of the literature. We use asset prices in an augmented Taylor rule as a benchmark linear model and then use various nonlinear models including smooth transition autoregressive (STAR) model to estimate reaction functions (van Dijk et al., 2002 and Martin and Milas, 2004).

Our main findings are as follows. First, the Bank of England responds to deviations of inflation from the target and the output gap as well as asset prices misalignments, as we find that the asset price augmented Taylor rule outperforms the simple rule. Among various asset prices under consideration, however, the policy response to the exchange rate misalignment is more prominent.

Second, we find that the aim of monetary policy is to keep inflation within a narrow range rather than pursuing a point target of 2.5% in practice. Policy only responded to inflation when expected inflation is in the outer regime. This implies that monetary policy is nonlinear and the policy response is asymmetric.

Third, the policy response to the output gap and the exchange rate misalignment is more acute when economy is in the inner inflation regime compared to a response to them when the economy is in the outer inflation regime.

The rest of this chapter is organized as follows. The next section discusses the contemporary literature and identifies the research gap. Section 3.3 presents the methodology followed by empirical findings in Section 3.4. Finally, section 3.5 concludes the chapter.

3.2 Evolution of monetary policy reaction function

John Taylor advanced the following monetary policy reaction function based on US quarterly data for the period of 1984.Q1 to 1992.Q3. Under this rule, short term interest rates are set in response to the deviation of inflation from the targeted rate and the output gap (Taylor, 1993).

$$i_t = r + \pi + \partial_\pi(\pi_t - \pi^T) + \partial_y y_t \tag{3.0}$$

where, i_t is the Federal funds rate, π_t is the annualized quarterly inflation rate, π^T is the targeted rate of inflation, y_t is the output gap defined as $(Y - Y^*)/Y^* * 100$, where Y is the real GDP and Y^* is the potential GDP. In his original model, the average Federal fund rate, r, and the long run inflation rate, π, are set at 2 percent each to meet the steady state economic growth of 2.2 percent. The targeted rate of inflation, π^T, is assumed to be the sample average, i.e. 2 percent, and the feedback parameters, ∂_π and ∂_y, set at 0.5 each.

The underlying model has three basic assumptions: first, the central bank uses short-term interest rates as the policy instrument. Second, the central bank can systematically use the interest rate to stabilize inflation and output. And lastly, the interest rate responds with fixed weights to the deviation of inflation from the target and the output gap (see also Taylor, 1999a and 1999b).

Although it is widely accepted that the Taylor rule captures the basic characteristics of monetary policy, at least for the inflation targeting countries, the scope of the use of the conventional rule is limited in practice for two reasons. First, monetary policy might be nonlinear and policy response could be asymmetric. Secondly, policy may not always respond to inflation and the output gap but also to other variables. The recent contributions, therefore, have addressed these two issues extensively which can be categorized under the linear and nonlinear monetary policy reaction functions as follows.

3.2.1 Linear reaction function

The experiment and extension of the conventional rule under the linear framework may be summarized as follows:

First, although the conventional Taylor rule provides a contemporary relationship among the short term interest rates inflation and the output gap, recent empirical studies suggest that either a backward looking or forward looking specifications better explains the behavior of monetary policy. Ball (1999), Svensson (1999), Rudebusch and Svensson (1999) are examples of backward looking models while Clarida et al. (1999), Domenech et al (2001) and Mehra (1999), among others, favor a forward looking policy reaction function. The literature, however, presents a consistent result that monetary policy across countries has been more responsive to inflation than any other policy variables since early 1990s.

Second, efforts have been made to simulate the liner policy rule using different time horizons and various structural macroeconomic models. Overall, the results show that the Taylor rule stabilizes inflation and output in a way close to optimal policy rules in many macroeconomic models (Ball 1999, Taylor, 1999a and Lansing and Trehan, 2001).

Third, as the conventional Taylor rule has been expanded by including asset prices and open economy variables like the foreign interest rates and the exchange rate. For instance, Gerlach (2004) expands the Taylor rule by including financial market conditions, proxied by the spread between the short-term Treasury bill rate and a long term risky bond for the US (see also Mehra[16], 1999). Gerlach and Schnabel (2000) and Clarida et al. (1998) include monetary growth and the exchange rate (see also Chadha et al. 2004). Smets (1997) uses the nominal trade-weighed exchange rate, a ten-year nominal bond yield and the stock market index in the Taylor rule for Canada and Australia. Adam et al. (2004), on the other hand, include foreign interest rates in a Taylor rule estimated for the UK.

Fourth, a survey of empirical studies show that policymakers give more weight to inflation than to the output gap in the inflation targeting regime compared to the previous era (see Domenech et. al, 2001, and Gerlach and Schnabel, 2000 for the Euro area; Nelson, 2000 and Martin and Milas, 2004 for UK and Judd and Rudebusch, 1998, Perez, 2001 and Orphanides, 2001 for the US).

Fifth, the literature argues that the smoothing Taylor rule, which considers a gradual adjustment of interest rates towards equilibrium, is more appropriate than the 'immediate reactive' policy rule, which does not consider the lag dependent in the reaction function, for the following reasons. Firstly, interest rate inertia allows the central bank to communicate its policy more clearly so that financial instability due

[16] He includes the long-term bond rate in the reaction function for the US.

arising from uncertainty in the monetary policy is minimized (see also Goodfriend 1987, 1991). Secondly, as discussed in Woodford (2001) and Clarida et al. (1998), a smoothing reaction function makes the future path of interest rates more predictable.

Thirdly, it is argued that uncertainty about the future state of the economy might encourage the central bank to change short-term interest rates gradually (see Orphanides, 1998, Judd and Rudebusch 1998). Finally, it is also argued that interest rate smoothing enable policymakers to avoid frequent policy reversals. This would make policy more credible as frequent policy reversals may jeopardize the financial stability (Goodhart, 1999). Therefore, interest rate smoothing is also viewed as an attempt by policymakers to safeguard their reputation (see also Kontonikas, 2004).

3.2.2 Nonlinear reaction functions

Although linear Taylor-type reaction functions give a basic framework for monetary policy analysis, they potentially neglect asymmetries and nonlinearities that may be important in practice. As discussed in Clark et al. (1997), if the economy itself is asymmetric then policy should also have an offsetting asymmetry. Mayes and Viren (2001) further argue that as long as the hypothesis of asymmetry cannot be convincingly rejected, policy should assume asymmetry because the cost of wrongly assuming symmetry when the economy is asymmetric are greater than from assuming it is asymmetric when actual policy is symmetric.

The literature finds at least two sources of nonlinearity in monetary policy. First, it is often argued that policymaker's preferences are asymmetric as they have to face a nonlinear loss function instead of the linear quadratic. This implies that the policymakers show different temptation for controlling positive and negative deviations of inflation from the target (see Gerlach 2000, Cukierman, 2000, Nobay and Peel, 1998, and Dolado et al. 2004 among others).

Secondly, it has been recognized that either the supply (Philips) and/or demand (IS) curve may be nonlinear which implies economic policy follows a nonlinear path. For instance Schaling (1999), and Dolado et al. (2003) argue that the Philips curve is convex to the origin. On the other hand, Stiglitz (1997) is in favor of concave Philips curve.

Huang et al. (2001), on the other hand, argue that the nonlinearity arises from uncertainty in the productivity. They find that an optimal updating rule for the NAIRU leads to nonlinear interest-rate policy in Finland. This implies that policymakers are more cautious about adjusting interest rates in response to a small output gaps than in a standard linear Taylor rule but more aggressive when they reach a certain threshold.

In this context, Orphanides and Wieland (2000) develop an optimal monetary policy reaction function based on nonlinear preferences. Ruge-Murcia (2002), Surico (2002) and Cukierman and Muscatelli (2002) also follow the same tradition, assuming asymmetric preferences with respect to inflation and/or the output gap. Employing an asymmetric loss function, Cukierman and Gerlach (2003) show that even if policymakers target the natural level of employment, there will be an inflation bias if the central bank is more sensitive to policy failures that drive employment below the normal level than to policy failures that raise employment above it. This suggests that policy measure is clearly nonlinear.

Nobay and Peel (1998) assume that the central bank has an asymmetric loss function with regards to both inflation and the output gap. They argue that the asymmetric loss in inflation results in an inflation bias, which can take either sign whilst the asymmetric preferences over output gap implies that reducing the target level of output to the natural rate does not eliminate the inflationary bias.

Dolado et al. (2003, 2004) derive optimal monetary policy rules accounting for uncertainty on the output gap. Using US quarterly data, they find that both sign and size asymmetries of uncertainty matter in the conduct of monetary policy. Gerlach (2002) includes the output gap volatility to the Taylor rule and finds that responding more strongly to recessions than to expansions creates an inflation bias. Moreover, he argues that output volatility keeps a positive relation to both inflation and recessions, implying a higher volatility invites a higher rate of inflation and recessions.

Bec et al. (2002) extended theoretical models proposed by Svensson (1997) and Clarida et al. (1998, 2000) by including positive and negative deviations of output from trend. They find that changes in short term interest rates are influenced by the state of the current and or expected state of the business cycle in the US, Germany and France.

Martin and Milas (2004) use a quadratic logistic smooth transition autoregressive (QL-STAR) model to analyze the nonlinearity and asymmetric behavior of UK monetary policy. Using quarterly data from 1972Q1-2000Q1, they argue that monetary policy is more responsive to inflation and correspondingly less to the output gap in the inflation targeting period as compared to the previous era. The response of policy to inflation is nonlinear as interest rates respond more to positive deviations of inflation form the target compare to negative deviations. Furthermore, they argue that the BoE has attempting to keep inflation within a range rather than pursuing a point target of 2.5%.

In conclusion, nonlinear monetary policy rules have been popular in recent years, not only because data supports the nonlinear framework but also because the behavior of policymakers itself is nonlinear. In this context Meyer (2000)[17] says:

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[17] Remarks by Governor Laurence H. Meyer on "Structural Change and Monetary Policy" at a Joint Conference of the Federal Reserve Bank of San Francisco and the Stanford Institute for Economic Policy Research, Federal Reserve Bank of San Francisco, San Francisco, California, March 3, 2000. The speech can be found at http://www.federalreserve.gov/boarddocs/speeches/2000/20000303.htm

"..... I believe that a nonlinear rule may dominate a linear specification..... such a nonlinear rule could be justified either by nonlinearities in the economy or by a non-normal distribution of policymakers' prior beliefs about the NAIRU. It is certainly easy to believe that there are nonlinearities in the economy in general and with respect to the Phillips curve in particular..."

3.3 Methodology

3.3.1 General strategy and modelling framework

This chapter models the UK monetary policy for the ongoing explicit inflation targeting regime, post-1992. Therefore, the analytical framework we consider in this chapter assumes that the aim of monetary policy is to target inflation using short-term interest rates as the main operating instrument. Moreover, the central bank is assumed to be autonomous, at least at the operational level, so it can set monetary instruments freely in order to achieve the objective.

We begin our analysis by estimating a simple linear reaction function that combines the interest rate, deviations of inflation from the target and the output gap. We, then, augment the function by including a set of financial variables such as real exchange rate, house prices, and share prices.

Using an augmented Taylor rule as a benchmark linear specification, we then estimate nonlinear reaction function using various nonlinear econometric models. We begin with the Escribano and Granger (1998), Escribano and Aparicio (1999) and Granger and Lee (1989) models to test whether there is any sign and/or size asymmetries of deviations of inflation from the target. Although these models provide an indication of nonlinearity, they are too simple to describe distinct regimes for inflation. Therefore, in order to analyze nonlinear and asymmetric policy behavior together, we employ the Smooth Transition Autoregressive (STAR) family of models[18].

3.3.2 Benchmark specification

3.3.2.1. Taylor rule

To begin with, we assume that the central bank sets the short-term interest rate in response to the future deviation of inflation from the target and the output gap, albeit gradually. Following Clarida et al., (1998, 2000) the monetary policy reaction function that we consider is:

$$i_t = bi_{t-1} + (1-b)i_t^* \tag{3.1}$$

$$i_t^* = \beta + b_\pi E_{t-1}(\pi_{t+n} - \pi^*) + b_y E_{t-1}(y_{t+n} - y_{t+n}^*) \tag{3.2}$$

[18] Chapter 5 describes the model in detail.

Where, i_t is the observed nominal interest rate, i_t^* is the desired interest rate, β is the equilibrium interest rate, E_{t-1} is the expectation formed at t given the information of t-1, π_{t+n} is the expected inflation at time t+n, π^* is the targeted rate of inflation, y_{t+n} is actual GDP at time t+n, y_{t+1}^* is the potential GDP at time t+n, and v_t is white nose error term. b_π and b_y are parameters to be estimated.

Eq. (3.1) is the first order partial adjustment function where the observed interest rate, i_t, is defined as a weighted average of the previous period rate and the desired interest rate. We employ the first order partial adjustment model but it can be extended up to n[th] order depending on the nature of data. For instance, Clarida et al. (1988) employ a second order partial adjustment model for the US reaction function while they use the first order partial adjustment model for the European countries including UK.

Combining Eq. (3.1) and (3.2), we obtain

$$i_t = \bar{i} + b_i i_{t-1} + (1-b_i)[b_\pi E_{t-1}(\pi_{t+n} - \pi^*) + b_y E_{t-1}(y_{t+n} - y_{t+n}^*)] + \varepsilon_t \qquad (3.3)$$

where $\bar{i} = (1 - b_i)\beta$ is the equilibrium interest rate, b_i is the degree of interest rate smoothening and assumed to be $0<b_i<1$[19] and ε_t is a stochastic error term which combines the forecast errors of inflation and output and the random error, v_t.

3.3.2.2. Augmented Taylor rule

Although, Eq. (3.3) is considered to be an improvement over the conventional Taylor rule, it has also some limitations. First, as pointed out by Kerr and King (1995), Bernanke and Woodford (1997) and Clarida et al. (1998), the policy rule may be a source of instability if b_π is below unity. Second, the policy rule may not work well in practice if relevant variables are omitted from the reaction functions. This implies that the Eq. (3.3) may be mis-specified.

In the context of UK, a number of variables like the real exchange rate, the real house prices and the real share prices have been considered to be relevant in the conduct of

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[19] When b_i=1, the Taylor rule collapses, implies that policymakers do not respond to inflation and the output gap. In the other extreme when b_i=0, the resulting function becomes a forward looking Taylor rule without lag dependent. In this case, the reaction function does not allow us to smooth changes in interest rate, indicating that the central bank has a perfect control over the short term interest rate. It also implies that the interest rate can be adjusted immediately to its target level as and when required. This situation, however, is less likely to happen in practice (see Clarida et al. 1998, and 2000, Castelnuovo, 2003, Svensson, 1997, Orphanides, 2002 among others for the detailed analysis).

monetary policy[20] (Goodhart and Hofmann 2001, 2003; Batini and Turnbull, 2000). We, therefore, include all these asset prices in the linear specification but select only the real exchange rate (RER) augmented Taylor rule for the nonlinear specifications for two reasons. First, the preliminary experiments suggest that the policy response to RER misalignment is higher than to any other asset prices[21]. Second, our sample size is not big enough to include all possible asset prices in nonlinear models.

Therefore, we consider the following augmented Taylor rule as a benchmark model for nonlinear estimates:

$$i_t = \bar{i} + b_i i_{t-1} + (1-b_i) * [b_\pi E_{t-1}(\pi_{t+n} - \pi^*) + b_y E_{t-1}(y_{t+n} - y^*_{t+n})$$
$$+ b_e E_{t-1}(e_t - e^*_t)] + \varepsilon_t \qquad (3.4)$$

where e_t is the real effective exchange rate, e^* is the equilibrium real exchange rate as approximated by the HP filter method. b_e is the feedback parameter of $e_t - e^*$ and is expected to be positive because an increase in e_t indicates the depreciation of national currency vis-à-vis foreign currencies.

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[20] The previous chapter provides evidence about this.

[21] The next section provides empirical evidence on this

Notice that ε_t is a linear combination of forecast errors of deviations of inflation from the target, the output gap and the exogenous disturbances. Therefore, it has to be orthogonal to variables included in the information set (say, Ω_t). A failure to reject orthogonality implies that lagged variables enter in the reaction function only to the extent that they forecast future inflation or output (Clarida et al., 1998 and 2000 and Chadha et al., 2004). Formally, the orthogonality condition can be written as

$$E[\{i_t - \bar{i} - b_i i_{t-1} - (1-b_i)\{b_\pi(\pi_{t+n} - \pi^*) + b_y(y_{t+n} - y^*_{t+n}) + b_e(e_t - e^*_t)\}\}|\Omega_t] = 0 \quad (3.5)$$

Eq. (3.5) is the orthogonality condition implied by Eq. (3.4) where Ω_t is the vector of all variables that are taken into consideration by the central bank when taking the monetary policy decision.

3.3.3 Nonlinear modelling

3.3.3.1. Size and sign asymmetries

After estimating the linear benchmark reaction function, that is Eq. (3.4), we then proceed to analyze various aspects of nonlinearities in the reaction function that are generated from deviations of inflation from the target, $\pi_{t+n} - \pi^*$.

We first use the Granger and Lee (1989) model to test for sign asymmetries. This model includes positive and negative deviations of inflation from the target separately (Dolado et al., 2000), it can be written as:

$$i_t = a + b_i i_{t-1} + (1-b_i)[b_{\pi,p}(\pi_{t+n} - \pi^*)^+ + b_{\pi,n}(\pi_{t+n} - \pi^*)^- + b_y(y_{t+n} - y^*_{t+n})$$

$$+ b_e(e_t - e^*_t)] + u_t \qquad (3.6)$$

Where, $(\pi_{t+n} - \pi^*)^+ = (\pi_{t+n} - \pi^*)$ if $(\pi_{t+n} - \pi^*) \geq 0$ and is zero otherwise, $(\pi_{t+n} - \pi^*)^- = (\pi_{t+n} - \pi^*)$ if $(\pi_{t+n} - \pi^*) < 0$ and is zero otherwise. $b_{\pi,p}$ and $b_{\pi,n}$ are the key parameters in this model. We test the null hypothesis $H_0 : b_{\pi,p} = b_{\pi,n}$ against $H_1 : b_{\pi,p} \neq b_{\pi,n}$ to identify the sign asymmetry. Rejecting the null implies that policymakers respond to positive and the negative deviations of inflation from the target differently. This model, however, simplifies to the linear model in Eq. (3.4) if we do not reject the null hypothesis.

We then estimate the Escribano and Granger (1998) and Escribano and Aparicio (1999) model to test whether there is any size effects of $\pi_{t+n} - \pi^*$ in the conduct of monetary policy. This type of model recently used by Arghyrou et al. (2005) to analyze inflationary dynamics for UK, Martin and Milas (2004) to examine monetary policy reaction function for UK; and Dolado et al. (2000) to test the output gap asymmetry for the US monetary policy reaction function. The model can be written as:

$$i_t = a + b_i i_{t-1} + (1 - b_i)[b_{\pi,1}(\pi_{t+n} - \pi^*) + b_{\pi,2}(\pi_{t+n} - \pi^*)^2$$
$$+ b_y(y_{t+n} - y^*_{t+n}) + b_e(e_t - e^*_t)] + u_t \quad (3.7)$$

Eq. (3.7) compares to (3.4) except for the term $b_{\pi,2}(\pi_{t+n} - \pi^*)^2$ where, $b_{\pi,2}$ measures the size asymmetry of deviations of inflation from the target. In this model, we test a null hypothesis, $H_0 : b_{\pi,2} = 0$ against the alternative $H_1 : b_{\pi,2} \neq 0$. Rejecting the null implies that policy responds differently for large and small deviations of inflation from the target, i.e. the size matters in the interest rate setting. The model simplifies to the linear benchmark reaction function in Eq. (3.4) if we do not reject the null hypothesis.

3.3.3.2. Smooth transition autoregressive models

The sign and size hypotheses as given by Eq. (3.6) and (3.7) are simple extensions of the linear reaction function. One of the limitations of them is that they do not describe the adjustment process even when the sign or the size of deviations of inflation from the target matters. Therefore, we next employ smooth transition autoregressive (STAR) family models to analyze whether monetary policy is nonlinear and policy response is asymmetric. This class of nonlinear models is flexible in nature and provides a number of alternative specifications (see Chapter 5 for more discussion).

As discussed in Granger and Terasvirta (1993), Terasvirta and Anderson (1992) and Terasvirta (1994), there are three steps to be followed to arrive at the final estimable STAR model. The first step is to test linearity. If it is not rejected then nonlinear model, especially STAR models, does not provide any better result over linear ones. Therefore, we only estimate the nonlinear reaction function using STAR models if linearity is rejected. The second step is to select a transition variable. This variable is the sources of nonlinearity in the model as we obtain regimes for this variable. The third step is to choose an appropriate transition function if there is a lack of economic theory to be used.

Formal linearity test

As discussed, a formal linearity test is required before employing any nonlinear models. In this context, we use the testing approach proposed by Saikonnen and Luukkonen (1988), Luukkonen et al. (1988), Granger and Terasvirta (1993), Terasvirta and Anderson (1992) and Terasvirta (1994). This test is based on the following artificial regression.

$$i_t = A + \beta_0 \phi_t + \sum_{j=0}^{\Phi} [\beta_{1,j} \phi_{t-j} (\pi_{t-d} - \pi^*) + \beta_{2,j} \phi_{t-j} (\pi_{t-d} - \pi^*)^2 + \beta_{3,j} \phi_{t-j} (\pi_{t-d} - \pi^*)^3] + \eta_t \quad (3.8)$$

Where, A is the constant term, ϕ_t is a vector of $\{ i_{t-1}, (\pi_{t+n} - \pi^*), (y_{t+n} - y^*_{t+n}), (e_t - e^*_t) \}$, η_t is a white nose error term and β_j (for j= 1 to k) are parameters to be estimated for different values of the delay parameter, d. The linearity test implies the testing of null hypothesis, H$_0$: $\beta_{1,j} = \beta_{2,j} = \beta_{3,j} = 0$ against alternative that at least one of them is non-zero. This can be done with a standard Lagrange Multiplier (LM) type test.

Selection of a transition variable[22]

As discussed earlier, the purpose of this chapter is to model the UK monetary policy for the explicit inflation targeting regime. Therefore, the main objective of estimating nonlinear reaction function using STAR model is to examine whether the size and/or sign of deviations of inflation from the target matters for the policy purpose and also to test whether there exists any asymmetric adjustment of this variable. In this light, we only consider $\pi_{t-d} - \pi^*$ as transition variable where d is the 'delay parameter'. We estimate Eq. (3.8) using a series of d such that $-n \le d \le n$ and report the linearity test for all values of d (van Dijk et al, 2002). The maximum number of d is set using the AIC and the partial autocorrelation of $\pi_t - \pi^*$ (Iregui et al., 2002).

[22] We consider the single transition variable in this chapter. The use of multiple transition variables can be found in Chapter5.

Finally, the decision rule is to choose the value of d that rejects linearity most decisively (van Dijk et al., 2002). If the linearity is rejected for more than one value of d, then we select the one which gives the lowest p-values (see Terasvirta and Anderson, 1992 for more discussion).

Selection of transition functions

The literature provides mainly two alternative transition functions for the STAR model. They are the logistic smooth transition function (LSTAR) and the quadratic logistic smooth transition function (QL-STAR). The former describes the sign asymmetry while the latter gives a size asymmetry of the transition variable[23]. There is a formal procedure for selecting one against another but we use both of them to estimate the nonlinear reaction function, as our sample is relatively small to rely on the test statistics.

[23] The literature also provides an exponential smooth transition function to describe the size asymmetry. However, as discussed in Iregui et al. (2002), van Dijk et al. (2002) and Martin and Milas (2004), the ESTAR model simplifies to the linear model if either $\gamma \to 0$ or $\gamma \to \infty$. For this reason, we do not estimate the nonlinear reaction function using exponential transition function.

Nonlinear reaction function

In the light of above discussion, we estimate the nonlinear reaction function using logistic function as given below (van-Dijik et al., 2002 and Martin and Milas, 2004):

$$i_t = \bar{i} + \rho i_{t-1} + (1-\rho)[\theta_t M_{Lt} + (1-\theta_t) M_{Ut}] + \xi_t \qquad \xi_t \sim iid(0,\sigma^2) \qquad (3.9)$$

Where,

$$M_{Lt} = k_{11}(\pi_{t+n} - \pi^*) + k_{12}(y_{t+n} - y^*_{t+n}) + k_{13}(e_t - e^*_t)$$

$$M_{Ut} = k_{21}(\pi_{t+n} - \pi^*) + k_{22}(y_{t+n} - y^*_{t+n}) + k_{23}(e_t - e^*_t)\text{, and}$$

$$\theta_t = \Pr\{\tau \ge (\pi_{t-d} - \pi^*)\} = 1 - \frac{1}{1 + e^{-\sigma(\pi_{t-d} - \pi^* - \tau]) / s_\pi}}, \sigma > 0$$

Eq. (3.9) is a nonlinear reaction function in which i_t is a weighted average of a "lower regime", M_{Lt} and an "upper regime", M_{Ut}, where M_{Lt} and M_{Ut} are augmented Taylor rules similar to Eq. (3.4). θ_t is the relative weights assigned to M_{Lt} and is bounded between 0 and 1. In this model, θ_t is the probability that $\tau \ge (\pi_{t-d} - \pi^*)$ and consequently (1-θ_t) is the probability that $\tau < (\pi_{t-d} - \pi^*)$. Therefore, the model describes the sign asymmetry of transition function, $\pi_{t-d} - \pi^*$.

The transition function, θ_t, is determined by the combination of the transition variable, $\pi_{t-d} - \pi^*$ and nuisance parameters (τ and σ). The first nuisance parameter, τ, is frequently referred to as the 'threshold parameter', while the latter one is the 'slope parameter'.

The slope parameter, σ, which determines the smoothness of the changes of transition from one regime to another, has important implication in this model. When $\sigma \rightarrow \infty$, θ_t becomes a heaviside function. In this case, θ_t=0 if $(\pi_{t-d} - \pi^*) \leq \tau$ and θ_t=1 if$(\pi_{t-d} - \pi^*) > \tau$. Secondly, when $\sigma \rightarrow 0$ the logistic function becomes constant and the model simplifies to be the basic linear model in Eq. (3.4). We make σ dimension free by dividing it by the standard deviation, s_π, of π_t (van Dijk et al., 2002; and Iregui et al., 2002 for more discussion).

The LSTAR model simplifies to the benchmark linear model in Eq. (3.4) if $k_{1j} = k_{2j}$ (for all j=1 to 3). There is a sign asymmetry in the reaction function if $k_{11} \neq k_{21}$. In practice, we expect $k_{11} < k_{21}$, $k_{21} > k_{22}$ and $k_{21} > k_{23}$ as policymakers give more attention to inflation and less to output gap and RER if $\pi_{t+n} > \pi^*$. This model, however, does not describe the size asymmetry.

We next estimate the nonlinear reaction function using the QL-STAR model as an alternative to the LSTAR model. This model also provides two regimes for inflation but the main difference between the LSTAR and QLSTAR is that the former provides the lower and upper regime while the latter gives the inner and outer regime. In the latter case, we consider the economy is in the inner inflation regime when expected inflation is close to the target or remains within two inflation boundaries. On the other hand, the economy remains in the outer inflation regime when expected inflation is below the lower boundary or exceeds the upper boundary.

The QL-STAR reaction function can be written as:

$$i_t = \bar{i} + \rho i_{t-1} + (1-\rho)[\theta_t M_{It} + (1-\theta_t) M_{Ot}] + \xi_t \tag{3.10}$$

Where,

$$M_{It} = k_{11}(\pi_{t+n} - \pi^*) + k_{12}(y_{t+n} - y^*_{t+n}) + k_{13}(e_t - e^*_t)$$

$$M_{Ot} = k_{21}(\pi_{t+n} - \pi^*) + k_{22}(y_{t+n} - y^*_{t+n}) + k_{23}(e_t - e^*_t) \text{ and}$$

$$\theta_t = \Pr\{\tau^L \leq (\pi_{t-d} - \pi^*) \leq \tau^U\} = 1 - \frac{1}{1 + e^{-\sigma(\pi_{t-d} - \pi^* - \tau^L)(\pi_{t-d} - \pi^* - \tau^U)/s_\pi}}, \sigma > 0$$

Eq. (3.10) describes i_t as a weighted average of the inner regime, M_{It}, and outer regime, M_{Ot}. There are two thresholds in this model, the lower threshold (τ^L) and the upper threshold (τ^U), which determines two distinct regimes. The model gives the inner inflation regime when $\tau^L \le (\pi_{t-d} - \pi^*) \le \tau^U$ and the outer regime otherwise. When economy is in the inner regime, the interest rate is determined by M_{It}. Similarly, the interest rate is determined by M_{Ot} when the economy is in the outer inflation regime.

In this model, the transition function θ_t has two important properties. First, θ_t becomes constant and hence model simplifies to the benchmark model in Eq. (3.4) when $\sigma \to 0$. Second, when $\sigma \to \infty$, θ_t=0 if $(\pi_{t-d} - \pi^*) \le \tau^L$ or $(\pi_{t-d} - \pi^*) > \tau^U$ and θ_t=1 when $\tau^L \le (\pi_{t-d} - \pi^*) \le \tau^U$. Following Granger and Tersvirta (1993) and Terasvirta (1994) we make the slope parameter dimension free by dividing it by the variance of inflation (s_π).

As in the LSTAR, The QL-STAR function simplifies to the linear benchmark model in Eq. (3.4) if $k_{1j} = k_{2j}$ (for all j=1 to 3). The size of deviations of inflation from the target matter if $k_{11} \ne k_{21}$. Monetary policy is asymmetric if we reject the null hypothesis $H_0 : [(\pi^* - \tau^L) + (\pi^* + \tau^U)]/2 = 2.5\%$ against an alternative hypothesis, $H_1 : [(\pi^* - \tau^L) + (\pi^* + \tau^U)]/2 \ne 2.5\%$.

3.4 Empirical estimates and discussion

3.4.1 The data

We model UK monetary policy for the ongoing inflation targeting regime, that is, 1992Q4 - 2004Q2. We use the three-month Treasury bill rate as the nominal interest rate, i_t and the four-quarter change in the retail price index (RPI) as the inflation rate, π_t. Similarly, real GDP is used as output, y_t and the trade weighted real effective exchange rate index (RER) as the exchange rate variable, e_t where an increase indicates depreciation of home currency vis-à-vis foreign currencies. All data are obtained from the International Monetary Fund provided by DataStream.

Although the official inflation target (π^*) varies over time in UK[24], we set it to 2.5%, a periodic average, throughout the period to make comparable with other studies (Martin and Milas, 2004, Clarida et al., 1998, and Nelson, 2000). In order to obtain the potential output and the equilibrium RER, we use the Hodrick-Prescott filter. The output gap ($y_t - y_t^*$) and the deviation of RER from the equilibrium ($e_t - e^*$) are, therefore, defined as the difference between the actual variable and the corresponding Hodrick-Prescott trend. The plots of variables are given in Figure 3.1, below.

[24] It was set to a range of 1% to 4% for October 1992 to April 1997 and 2.5% thereafter (Bernake et al. 1999).

We employ augmented Dickey-Fuller (1979) and Phillips-Perron (1988) tests to assess the stationary of the variables. As discussed in the previous chapter, while the former test makes a parametric correction for higher-order serial correlation by assuming that the series follows an autoregressive process with order AR(P) and adjusts the test methodology by adding lags of independent variables, the latter tests a unit root through a non-parametric correction procedure (Benerjee et al., 1993).

Table 3.1 presents the test results. The order of integration of i_t is found to be more ambiguous but following Clarida et al. (1998), Martin and Milas (2004) and Fuhrer (1997), among others, we consider this variable as stationary. Other three variables ($\pi_t - \pi^*$, $y_t - y_t^*$ and $e_t - e^*$) are found to be stationary at 1%.

Moreover, the literature argues that the linear unit root tests (ADF and PP tests) are less powerful to detect the stationarity if variables take a nonlinear adjustment process (Gregoriou and Kontonikas, 2006). In this context, the recent theory and the empirical literature related to the purchasing power parity, real exchange rates and monetary policy rule (eg. Sarantis, 1999, Chortareas et al. 2002 and Martin and Milas, 2004) suggest that inflation and the real exchange rates follow a non-linear mean reverting process in which case the linear unit root tests may be insufficient to test the stationarity. Therefore, following Kapetanious et al. (2003), we employ an exponential smooth transition autoregressive unit root test to evaluate stationarity process for $\pi_t - \pi^*$ and $e_t - e^*$. The detail methodology is given in Appendix 2.2. The empirical estimates firml y suggest that there is no need to doubt about the sationarity of both variables as we obtain sufficiently a high t-ratio[25].

Table 3.1: Unit root tests (1992Q4 – 2004Q2)

Variable Name	Description	ADF Test	PP Test
i_t	3 Month Treasury Bill Rate	-2.58***	-2.19
$\pi_t - \pi^*$	4 quarter change in retail price index (RPI) less the target (2.5%)	-3.77*	-2.96**
$y_t - y_t^*$	Output gap	-3.99*	-3.99*
$e_t - e_t^*$	RER misalignment	-7.09*	-6.98*

Note:

(a) y_t^* and e_t^* are Hodrick- Prescott trends with smoothing parameter set at 1600.

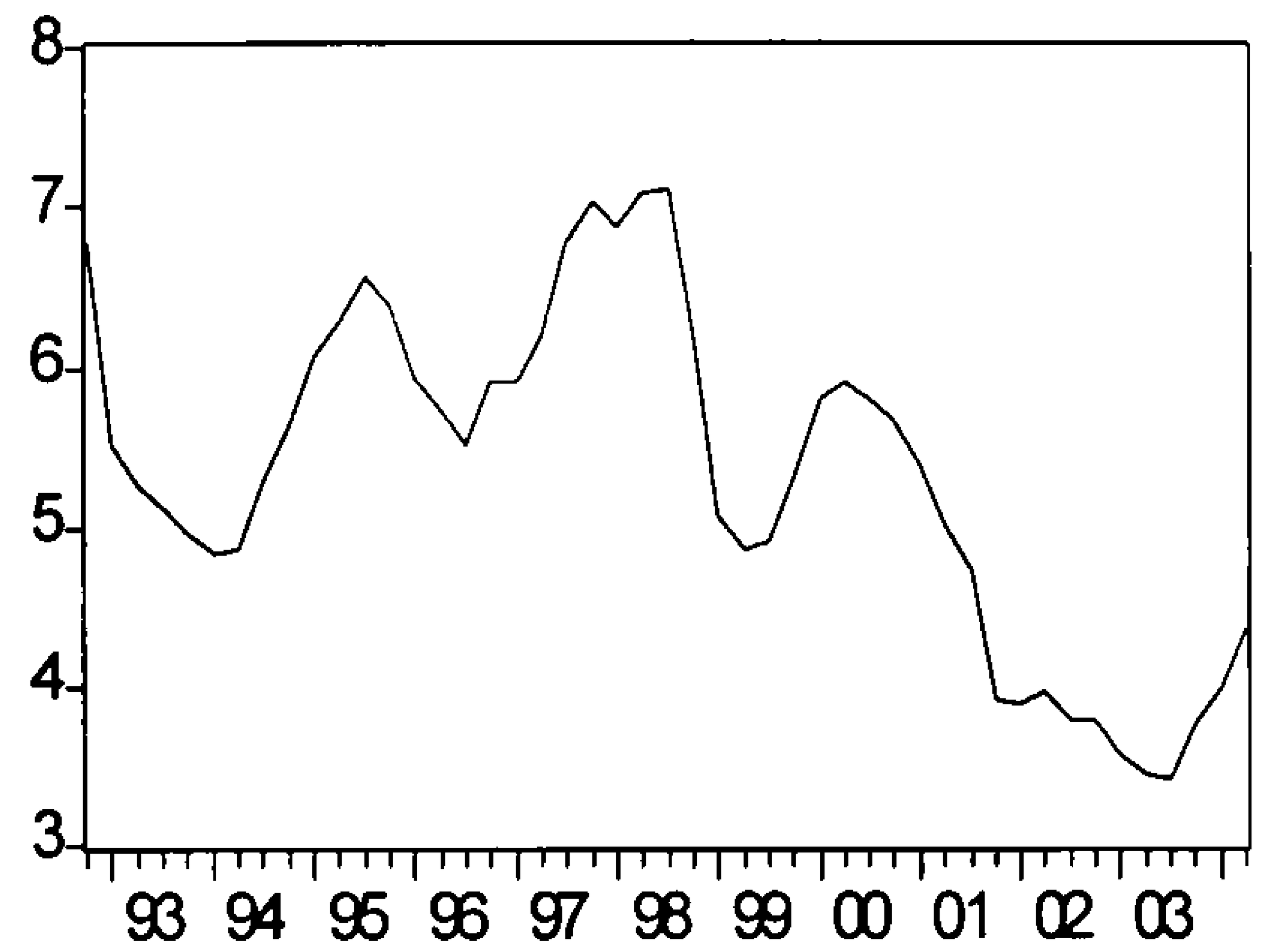
(b) Critical values for the ADF and PP-Test are -3.57, -2.92 and -2.60 at 1%, 5% and 10% significance level respectively.

*(c) The superscripts *, ** and *** in column (iii) and column (iv) indicate significant at 1%, 5% and 10% respectively.*

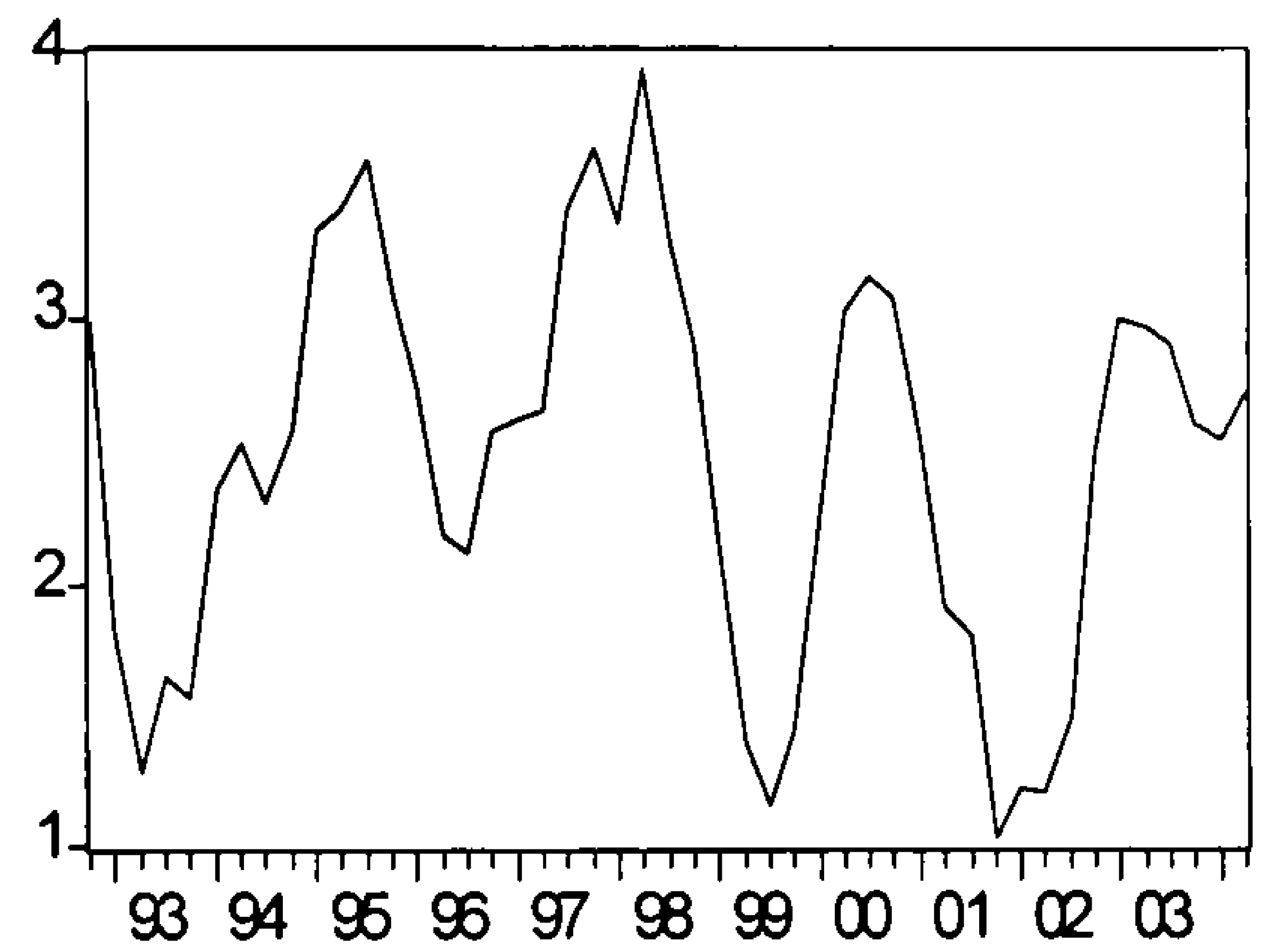
[25] The computed t-ratio for the coefficients of the cubic $\pi_t - \pi^*$ and $e_t - e^*$ are 5.98 and 7.87 respectively.

Figure 3.1: Plots of variables

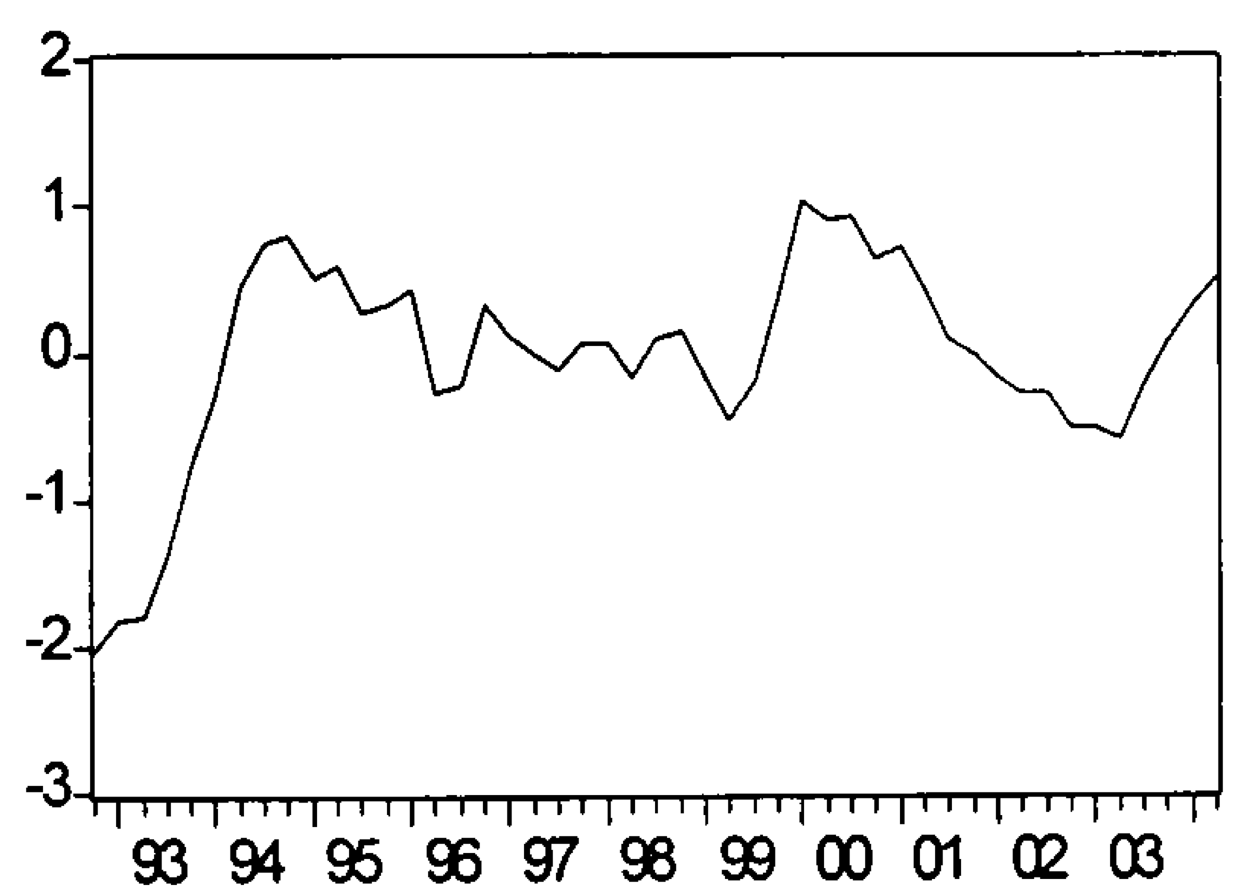
a. Three-month Treasury bill rate, i_t



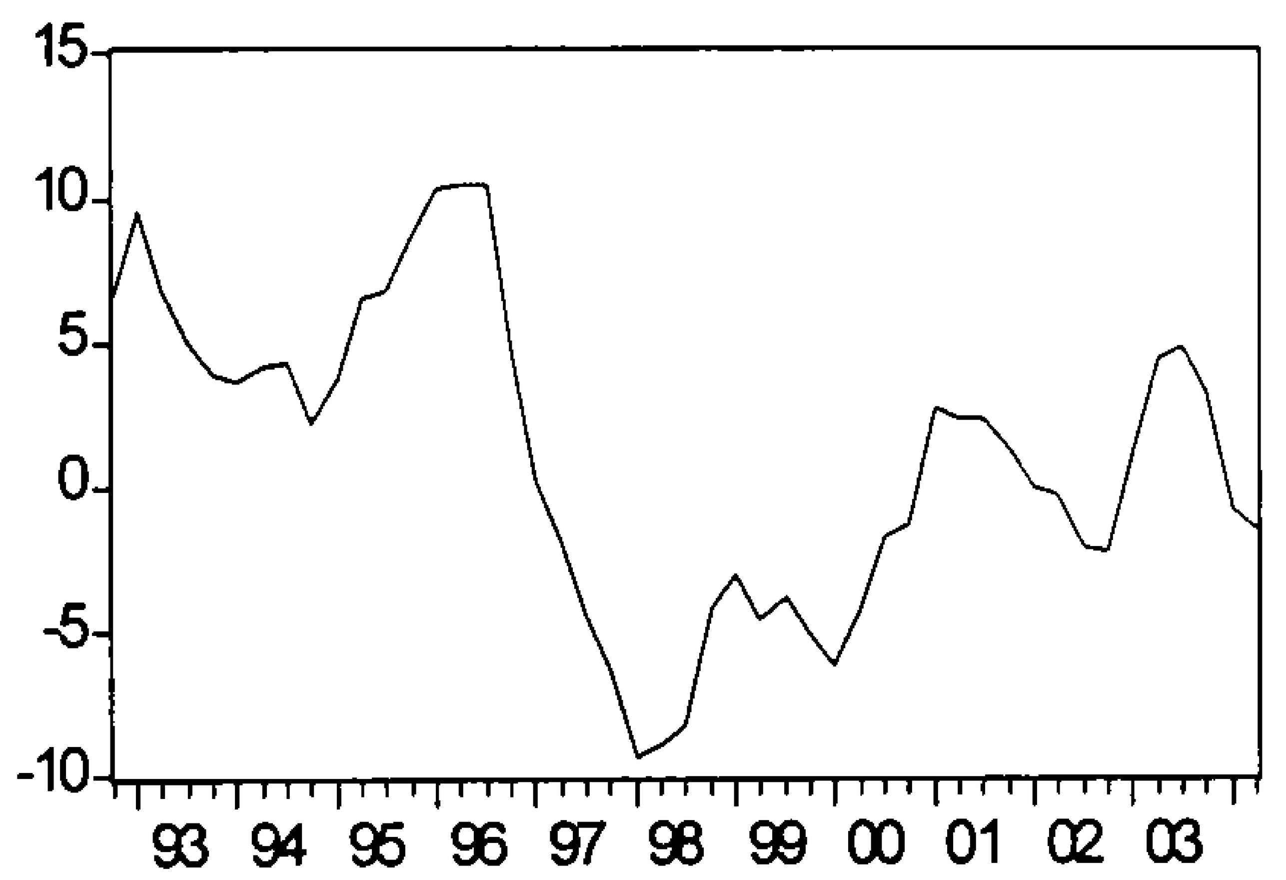
b. RPI Inflation, π_t



c. Output gap, $y_t - y_t^*$



d. RER misalignment, $e_t - e_t^*$



3.4.2 Linear estimates

We begin our empirical analysis by estimating Eq. (3.3) by GMM and OLS. We experiment various time horizons for the explanatory variables ranging from the 4th quarter lag to 4th quarter lead ($-4 \leq n \leq 4$). Empirical estimates[26], however, reveal that the one period ahead forward looking smoothing Taylor rule outperforms other specification irrespective of the estimation method. Therefore, unless otherwise stated, we use n=1 for inflation and the output gap and n=0 for the RER as time horizon of variables for all reported estimates. This is consistent with many empirical studies (eg. Clarida et al., 1998, Chadha et al. 2004 and Adam et al. 2005).

Estimates of Taylor rule (Eq. 3.3) are presented in columns (i) and (ii) of Table 3.2 where the Column (i) presents OLS estimates and column (ii) provides GMM estimate. Consistent with the empirical literature (Martin and Milas, 2004, Clarida et. al., 1998 and Nelson, 2000) our GMM and OLS estimates satisfy the dynamic stability criterion since b_π is found to be greater than 1, parameters are significant at 1% with expected positive sign and the condition $b_\pi > b_y$ is satisfied. Also i_t is found to be highly persistent as b_i is close to 0.9. This all implies that the Bank of England has given more weight on the price stability and correspondingly less weight on the output stability during the ongoing inflation targeting era.

[26] Not all of them are reported to save space but are available on request.

Table 3.2: Estimates of linear reaction functions (1992Q4-2004Q2)

Variables	Estimate of Eq. (3.3)		Estimate of Eq. (3.4)	
	OLS (i)	GMM (ii)	OLS (iii)	GMM (iv)
$\bar{i}$	0.62 (0.220)*	0.83 (0.085)*	0.576 (0.202)*	0.768 (0.109)*
b_i	0.87 (0.040)*	0.84 (0.015)*	0.879 (0.036)*	0.841 (0.020)*
b_π	2.50 (0.799)*	2.35 (0.223)*	2.233 (0.713)*	1.447 (0.246)*
b_y	1.76 (0.837)**	1.16 (0.421)*	1.606 (0.781)*	1.127 (0.378)*
b_e			0.139 (0.058)*	0.124 (0.009)*
$\overline{R}^2$	0.87	0.86	0.89	0.88
s.e.	0.36	0.37	0.34	0.35
LM4	1.38 [0.25]		1.21 [0.32]	
ARCH4	1.96 [0.11]		1.26 [0.30]	
F-H	1.54 [0.18]		0.63 [0.74]	
F-xH	2.01 [0.06]		0.54 [0.88]	
Normality	2.04 [0.35]	1.85 [0.39]	1.03 [0.59]	0.38 [0.42]
J-P statistics		0.18		0.20
p-value		0.89		0.92

Notes:

a. *Figures in parenthesis are standard error. *, ** and *** indicate level of significance at 1%, 5% and 10% respectively. Numbers in square brackets are p value of the test statistics. The interest rate, deviations of inflation from the target and the output gap are considered to be endogenous variables.*

b. *s.e. is the standard error of the regression. LM4 is the fourth order Breusch-Godfrey's Lagrange Multiplier F-test for the residual serial correlation. ARCH4 is the fourth order auto regression conditional heteroscadasticity F-test. F-H is the White's heteroscadasticity F-test of residual while F-xH is the test of cross heteroscadasticity. Finally, RESET is specification error test of the regression* *due to Ramsey (1969). P-value is the probability that the over identified restriction is satisfied under null.*

c. *As in Clarida et al. (1998) instruments used for GMM estimates are a constant and up to five lags of all variables used in the reaction function.*

Our GMM estimate is robust as we do not reject the null hypothesis that the overidentifying restriction is satisfied. The OLS estimates has heteroscadasticity effects, albeit, marginally.

We next estimate the RER augmented Taylor rule as given by Eq. (3.4). The estimates are presented in columns (iii) and (iv) of Table 3.2. We estimate b_e=0.12 by GMM in Column (iv) and 0.14 by OLS in Column (iii), both are significant at 1%, both imply that policymakers not only respond to deviations of inflation from the target and the output gap but also to deviations of RER misalignment. Also, these estimates do not alter the main findings of the simple Taylor rule as discussed earlier.

The augmented Taylor rule outperforms the simple rule for two reasons. First, standard error has improved significantly in the augmented model. Second, there is no misspecification in the estimates. Therefore, a RER misalignment augmented Taylor rule is our preferred estimate over the simple Taylor rule.

As discussed in the previous chapter, share prices and house prices are also considered to be important variables for UK monetary policy. Therefore, we estimate

Eq. (3.4) by including deviations of house price from the trend ($h_t - h_t^*$) and deviations of share prices from the trend ($s_t - s_t^*$) as an alternative specification to Eq. (3.3) and (3.4). The specification of more expanded Taylor rule is as follows:

$$i_t = a + b_t i_{t-1} + (1-b_t)*[b_\pi(\pi_{t+1} - \pi^*) + b_y(y_{t+1} - y_{t+1}^*) + b_e(e_t - e_t^*)$$

$$+ b_h(h_t - h_t^*) + b_s(s_t - s_t^*)] + \varepsilon_t \qquad (3.4a)$$

Where, h_t^* and s_t^* are obtained using the Hodrick-Prescott trend as usual[27].

Table 3.3 presents the empirical estimates of (3.4a). We observe that deviations of house prices from the trend, $h_t - h_t^*$, and deviations of share prices from the fundamental, $s_t - s_t^*$, significantly and positively enter in the reaction function without altering the previous findings. The estimates, both by GMM and OLS, confirm that the response to deviations of inflation from the target is more vigorous followed by the output gap, RER misalignment, deviation of house prices from the trend and the deviation of share prices from fundamentals[28]. This result is consistent with the previous chapter and further justifies the use of asset prices in the conduct of monetary policy[29].

[27] The sources and further definitions of variables are given in Chapter 2.

[28] This finding is fairly consistent with Goodhart and Hofmann (2001).

[29] The expanded Taylor rule may be considered as an alternative to the FCI augmented Taylor rule as discussed in the previous chapter. It is because the FCI includes all asset prices that are considered in the expanded Taylor rule. The FCI augmented Taylor rule was superior over the simple rule in the

Table 3.3: The estimates of expanded Taylor rule# (1992Q4-2004Q2)

	OLS Estimate	GMM Estimate
$\bar{i}$	0.444 (0.201)*	0.321 (0.059)*
b_i	0.905 (0.036)*	0.908 (0.011)*
b_π	2.550 (0.872)*	2.152 (0.305)*
b_y	1.632 (0.836)*	1.394 (0.180)*
b_e	0.132 (0.159)*	0.116 (0.059)*
b_h	0.031 (0.012**	0.052 (0.028)**
b_s	0.044 (0.020)**	0.059 (0.022)**
Diagnostic tests		
$\bar{R}^2$	0.88	0.88
s.e.	0.33	0.35
LM4	1.50 [0.21]	
ARCH4	1.75 [0.15]	
F-H	0.75 [0.68]	
Normality	0.15 [0.92]	2.44 [0.29]
J-P		0.19
p-value		0.989

Notes: # Estimate of Eq. 3.4a. See Table 3.2 for the footnotes.

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previous chapter while expanded Taylor rule outperformed the simple rule in this chapter, both justified the role of asset prices in the conduct of monetary policy in UK.

Despite this fact, we, however, do not include house prices and share prices in the nonlinear estimates for three reasons. First, the estimate of the extended Taylor rule does not provide a remarkable improvement over the RER augmented reaction function as the standard error of the estimate has decreased only marginally. Second, the response of interest rate to asset prices is almost negligible although the coefficients are significant. Third, our sample size is relatively small to include all possible asset prices in a nonlinear reaction function. We, however, address the issues of asset prices in the following chapters.

3.4.3 Nonlinear estimates

3.4.3.1 Accounting for sign and size asymmetries

The benchmark linear Taylor rule suggests that the deviation of expected inflation from the target, $E_{t-1}(\pi_{t+1} - \pi^*)$, is the most influential variable followed by the expected output gap, $E_{t-1}(y_{t+1} - y^*_{t+1})$, and the RER misalignment ($e_t - e^*_t$). We now proceed to analyze whether the sign and/or size of the deviation of inflation from the target matter in the conduct of monetary policy by estimating Eq. (3.6) and (3.7).

Table 3.4: Tests of size and sign effects (OLS Estimates: 1992Q4-2004Q2)

Coefficients	Sign effect (Estimate of Eq. 3.6)	Size effect (Estimate of Eq. 3.7)
$\bar{i}$	0.532 (0.180)*	0.565 (0.186)*
b_i	0.854 (0.033)*	0.861 (0.034)*
$b_{\pi,p}$	3.847 (0.957)*	
$b_{\pi,n}$	0.552 (0.6548)	
$b_{\pi,1}$		2.327 (0.586)*
$b_{\pi,2}$		1.017 (0.488)**
b_y	2.128 (0.667)*	2.128 (0.415)*
b_e	0.113 (0.042)*	0.115 (0.056)*
Diagnostic tests		
$\bar{R}^2$	0.92	0.92
s.e.	0.27	0.28
LM4	1.79 [0.15]	0.82 [0.53]
ARCH4	1.61 [0.18]	1.46 [0.22]
F-H	1.17 [0.33]	0.82 [0.59]
F-Xh	1.16 [0.35]	0.85 [0.63]
Normality	1.81 [0.40]	0.76 [0.62]
RESET	1.07 [0.30]	1.26 [0.26]
No asymmetry (H_0: $b_{\pi,p} = b_{\pi,n}$)	6.02 [0.00]	
No Size effects (H_0: $b_{\pi,2}$ =0)		4.34 [0.04]

Notes: Please refer to Table 3.2 for the footnotes.

Columns (i) of Table 3.4 presents the estimate of Eq. (3.6). We estimate $b_{\pi,p}$= 3.85 and $b_{\pi,n}$=0.55. As $b_{\pi,p}$ is significant at 1% but $b_{\pi,n}$ is insignificant, it is obvious that we reject the null hypothesis $H_0 : b_{\pi,p} = b_{\pi,n}$ in favor of alternative $H_1 : b_{\pi,p} \neq b_{\pi,n}$. This suggests that monetary policy is nonlinear and policy only responds to inflation when expected inflation exceeds the target. The policy response to the output gap and the RER misalignment is found to be similar with the linear estimates.

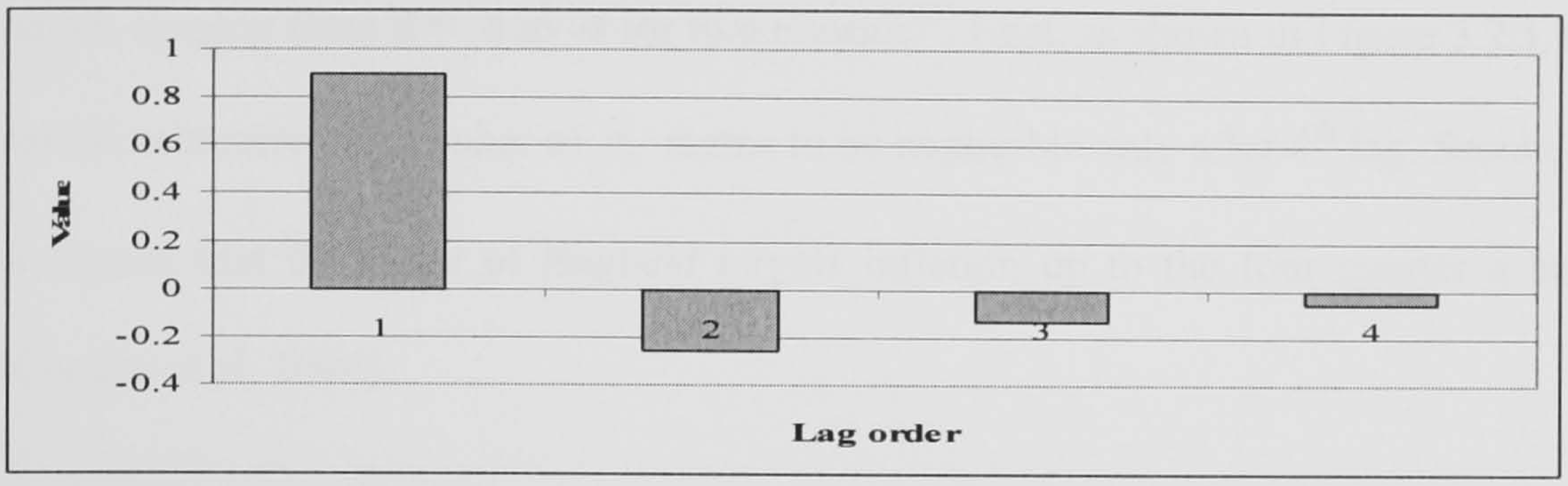
We next estimate the Escribano-Granger (1998) and the Escribano and Aparicio (1999) model, given by Eq. (3.7), which allows size asymmetries. The estimate of this model is presented in the last column of Table 3.4. In this case, we estimate $b_{\pi,2}$= 1.02 and reject the null hypothesis that $H_0 : b_{\pi,2}$=0 against the alternative $H_1 : b_{\pi,2} \neq 0$ at 1%. The estimates of other parameters are also fairly consistent with the previous estimates.

3.4.3.2 Formal nonlinearity tests

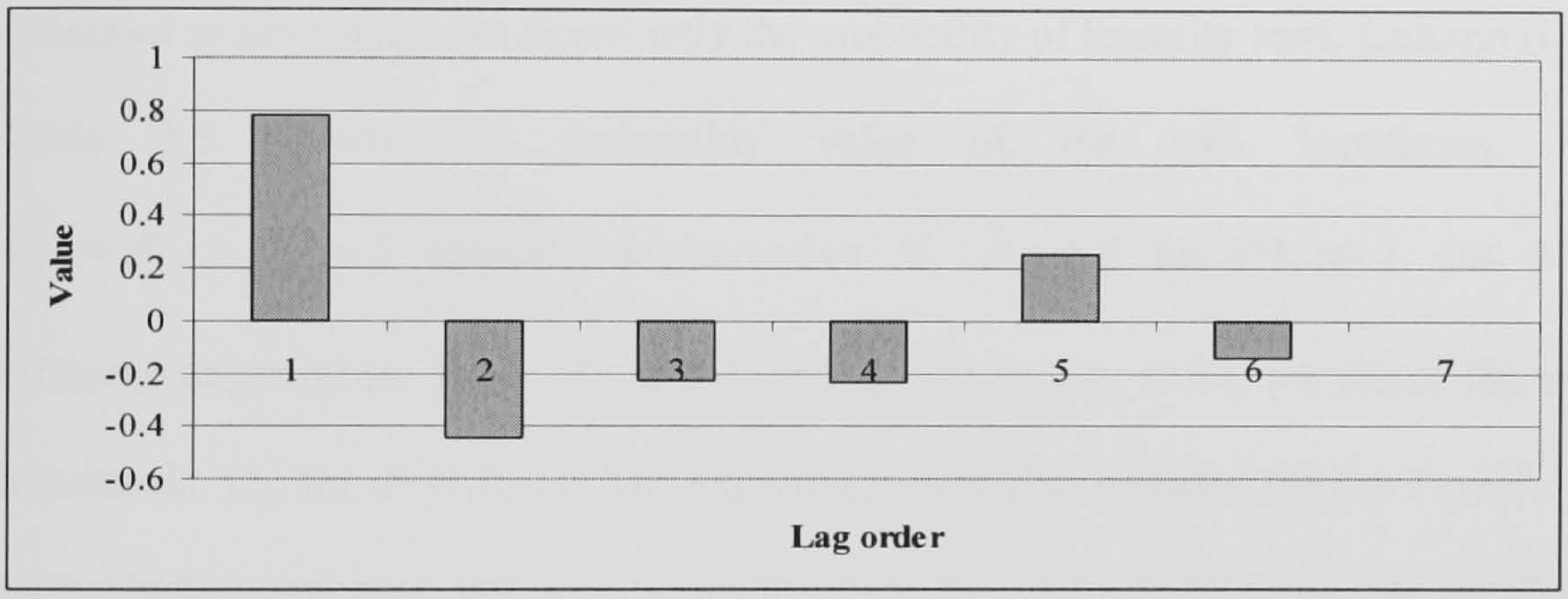
The estimate of Granger and Lee (1989) and Escribano-Granger (1998) models suggest that monetary policy in UK may be nonlinear but as discussed earlier they do not provide a decisive level of nonlinearity. We now proceed to test the (non)linearity formally by estimating Eq. (3.8).

Figure 3.2: Plots of partial autocorrelation

A. Dependent variable, i_t



B. Transition variable, π_{t-d}



There are two crucial parameters in this model, ϕ and π_{t-d}. It is suggested that the partial autocorrelation or alternatively Akaike information criterion can be used to determine the maximum possible number of Φ (Iregui et al., 2002 and van Dijik et al., 2002 for the detail discussion). We choose ϕ=1 not least because the partial autocorrelation of i_t almost dies after the first lag (see Figure 3.2A) but also because the first order smoothing function provides a better estimate of reaction function compared to any higher order (Clarida et al. 1988).

Regarding the delay parameter of the transition variable, π_{t-d}, we conducted a grid search ranging from d = 4 to -4 for two reasons[30]. First, as shown in Figure 3.2B, the partial autocorrelation value of π_t seems to be negligible only after 4th lag. Second, it is argued that the Bank of England targets inflation up to the four quarter a head (Chadha et al. 2004).

We estimated Eq. (3.8) for $-4 \le d \le 4$ and ф =1. We do not report the detailed estimates to save space but report only the probability of linearity tests. Column (i) of Table 3.5 reports the probability value of the null hypothesis, H_0: $\beta_{1,j} = \beta_{2,j} = \beta_{3,j} = 0$ against the alternative $H_1 : \beta_{i,j} \neq 0$ for i=1 to 3. Out of 9 different experiments [for $-4 \le d \le 4$ and ф =1] in Eq. (3.8), we reject the null hypothesis, H_0, for d={1,0,-1}. The experiment was also repeated for the Taylor rule by excluding exchange rate misalignments from Eq. (3.8). In this case we reject the null hypothesis for d={2,1,0-1}. However, the linearity is rejected most strongly using d=-1 for both the Taylor rule and the augmented Taylor rule.

[30] As in Sarantis (1999), we could use an AIC and/or Schwartz criterion to select the candidate of delay parameter if we have relatively a large sample size and if we do not consider a forward looking transition variable.

These formal hypothesis tests confirm that monetary policy in the UK is nonlinear and the π_{t+1} is the most appropriate transition variable to be used in the LSTAR and QLSTAR models as we reject linearity most strongly using d=-1.

Table 3.5: Formal linearity test* (1992Q4-2004Q2)

(Null hypothesis H$_0$: $\beta_{1,j} = \beta_{2,j} = \beta_{3,j} = 0$ against alternative of nonzero)

Transition variable	Φ	Augmented Taylor Rule (i)	Taylor Rule (ii)
π_{t+1}	1	0.006	0.011
π_t	1	0.035	0.018
π_{t-1}	1	0.009	0.019
π_{t-2}	1	0.128	0.061

*Notes: * Based on the estimate of Eq. (3.8). Numbers in the last two columns are the p value of LM test.*

3.4.3.3 Estimates of nonlinear reaction functions using STAR models

After confirming nonlinearity and selecting an appropriate transition variable we finally proceed to estimate nonlinear monetary policy reaction functions using L-STAR and QL-STAR models.

Table 3.6: Estimates of nonlinear monetary policy reaction function (1992Q4-2004Q2)

	L-STAR (Eq. 3.9)	QL-STAR (Eq. 3.10)
$\bar{i}$	0.448 (0.174)*	0.350 (0.179)**
ρ	0.885 (0.031)*	0.907 (0.032)*
	M_L	M_I
k_{11}	0.834 (0.606)	1.207 (0.939)
k_{12}	2.326 (0.990)*	2.726 (1.323)*
k_{13}	0.148 (0.063)*	0.128 (0.010)*
	M_U	M_O
k_{21}	4.200 (1.206)*	5.538 (2.088)*
k_{22}	2.430 (1.040)*	2.552 (1.323)**
k_{23}	0.044 (0.022)**	0.092 (0.032)**
τ	-0.310 (0.009)*	
τ^L		-1.074 (0.218)*
τ^U		0.370 (0.031)*
σ	144.7 (203.4)	89.2 (921.6)
Diagnostic Tests		
$\bar{R}^2$	0.93	0.94
n_s.e.	0.23	0.22
SE Ratio	0.65	0.62
AIC	0.09	0.10
D-W Statistics	1.97	2.06
LM4	1.01 [0.42]	1.44 [0.24]
ARCH4	1.40 [0.24]	0.09 [0.98]

Heteroskedasticity	0.54 [0.84]	1.17 [0.34]
Normality	1.57 [0.45]	1.07 [0.58]
Hypothesis Testing		
a. Test against Linear model: $k_{1i} = k_{2i}$	10.01 [0.00]	13.00 [0.00]
b. Inflation Persistence: $k_{11} = k_{21}$	6.94 [0.01]	8.16 [0.00]
c. Policy symmetric: $\pi^* = (\pi^* - \tau^L + \pi^* + \tau^U)/2$		27.0 [0.00]
d. No effective lower band: τ^L =0		32.3 [0.00]
e. No effective upper band: τ^U =0		24.0 [0.00]

Notes:

(a) n_s.e. is the standard error of the estimate

(b) SE Ratio = n_s.e./s.e where s.e. is the standard error of the linear reaction function which is obtained from Column 3, Table 3.3.

(c) Please see section 3.3.2 and footnotes of Table 3.2 for the remaining footnotes.

Column 2 of Table 3.6 presents the L-STAR estimate, that is the estimate of Eq. (3.9). In this model, the interest rate, i_t, is jointly determined by the upper regime (M_{Ut}) and the lower regime (M_{Lt}). We estimate, τ = -0.31% which provides inflation threshold ($\pi^* - \tau$) to be 2.19%. This implies that the economy is in the upper inflation regime when π_{t+1}>2.19% and consequently in the lower regime otherwise.

We find that policy does not respond to inflation when the economy is in the inner inflation regime as we find k_{11} is insignificant. Instead, policy responds to the output gap and RER misalignment. On the other hand, policy response to deviations of inflation from the target becomes vigorous followed by the output gap and the real exchange rate misalignment when economy is in the upper inflation regime. Notice that response to the output gap and the RER misalignment becomes more strong in the lower inflation regime compared to the response in the upper regime as we find $k_{12} > k_{22}$ and $k_{13} > k_{23}$.

The diagnostic tests suggest that there is no sign of misspecification though σ is found to be insignificant[31]. The DW statistics rejects the null of a unit root whilst the Godfrey's (Godfrey, 1988) lagrange multiplier (LM) test suggests that there is no autocorrelation in the residual. Moreover, the non-normality of null hypotheses is rejected by Jarque-Bera's test and an evidence of homoscadesticiy is clearly established. Also, no signal of auto regressive conditional heteroscadesticity appears from the fourth order condition.

Hypothesis tests suggest that the monetary policy reaction function is nonlinear because we reject the null of linearity, $H_0 : k_{1i} = k_{2i}$ for i=1 to3 against the alternative

[31] Terasvirta (1994) and Van Dijik et al. (2002) argue that it should not be interpreted as an evidence of weak estimate because an accurate estimation of σ is quite difficult in practice which requires many observations in the immediate neighborhood of the threshold parameter. Also, a large change in σ have only small effect on the shape of the transition function implying that high accuracy in estimating σ is not necessary (see also Iregui et al. 2002)

$H_1 : k_{1l} \neq k_{2l}$ at 1% significance level. Similarly, the persistence of inflation is found to be different between regimes as we reject the null hypothesis $H_0 : k_{11} = k_{21}$ against the alternative of $H_1 : k_{11} \neq k_{21}$; k_{11} is not found to be significant[32].

Panel A of Figure 3.3 shows the plot of inflation and threshold against the time. There are three main episodes (1993, 1999 and 2003) when expected inflation was below the threshold. Expected inflation was above the threshold in other period but it was remarkably noticed in early 1995, 1998 and 2000.

We next estimate the QL-STAR model, that is, Eq. (3.10) and the empirical results are presented in the last column of Table 3.6. We estimate $\tau^L = -1.074\%$, $\tau^U = 0.37\%$ and reject the null hypothesis of policy symmetry, $H_0 : \pi^* = (\pi^* - \tau^L + \pi^* + \tau^U)/2 = 2.5\%$, against the alternative $H_1 : \pi^* \neq (\pi^* - \tau^L + \pi^* + \tau^U)/2$ at 1%. We also reject the null of no effective lower boundary, $H_0 : \tau^L = 0$, and the null of no effective upper boundary, $H_0 : \tau^U = 0$, both at 1% significance level. This all imply that the policy response is clearly asymmetric and the BoE is trying to keep inflation within a range of 1.4% (=2.5-1.074) to 2.87% (=2.5+0.37) rather than hitting the target of 2.5% preciously.

[32] These tests, however, need to be treated with care because the test statistics do not follow standard distribution under the null hypothesis (Gregoriou and Kontonikas, 2006) .

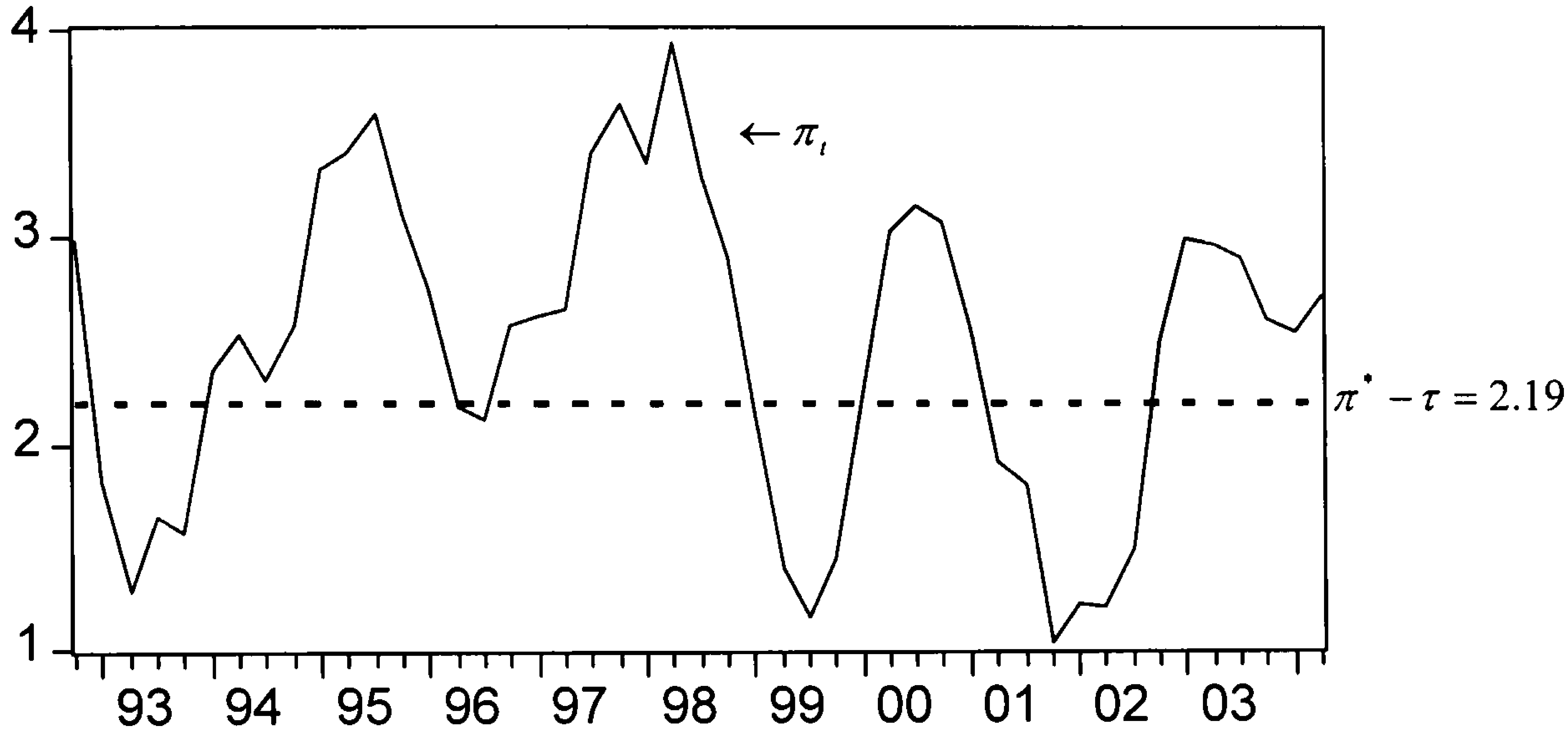
Further, we find that $k_{21} > k_{11}$, where k_{11} is insignificant, but $k_{12} > k_{22}$ and $k_{13} > k_{23}$, implies monetary policy is aggressive to inflation when expected inflation remains in the outer regime (see Martin and Milas, 2004). On the other hand, the policy response to $y_{t+1} - y^{*}_{t+1}$ and $e_t - e^{*}_t$ is stronger when expected inflation is in the inner inflation regime. Also, this model does not simplify to the benchmark model in Eq. (3.4) as we reject the null hypothesis $H_0 : k_{1j} = k_{2j}$ (for all j=1 to 3) at 1% against $H_1 : k_{1j} \neq k_{2j}$.

The QL-STAR estimate is robust and it is our preferred estimate among nonlinear estimates because it has the lowest standard error than any other estimates in this chapter.

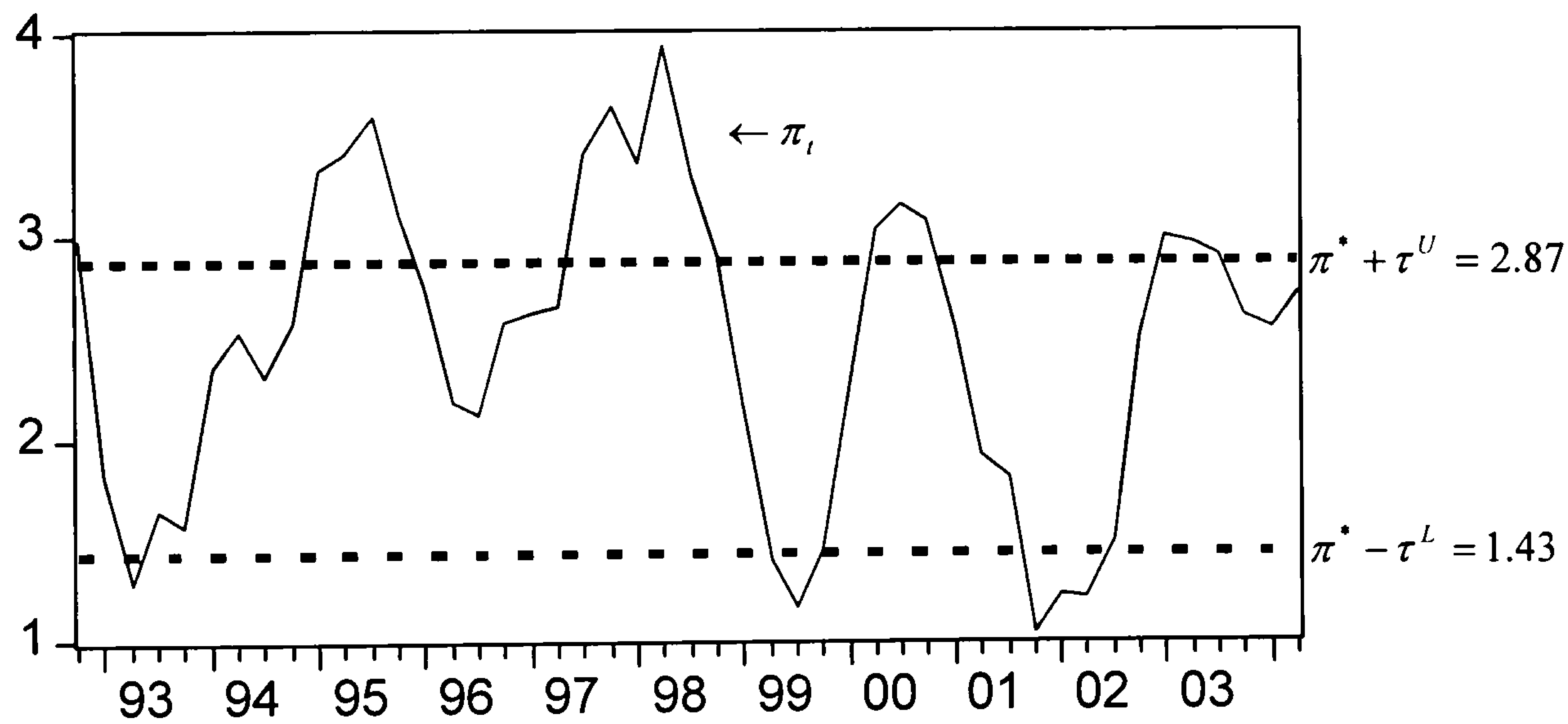
Panel B of Figure 3.3 plots the thresholds and inflation against time. It can be observed that inflation remained close to the target, i.e. within the regime boundaries, for most of the period except for 6 small departures from the boundaries during this period.

Figure 3.3: Plots of inflation against thresholds

A. Plots of inflation and threshold (Based on the LSTAR estimate)



B. Plots of inflation and thresholds (Based on the QL-STAR estimate)



To sum up, the estimate of the LSTAR and QL-STAR reaction functions suggest that the monetary policy in UK is nonlinear and that the policy response is asymmetric. It also highlights the fact that the RER misalignment comes positively and significantly in the monetary policy reaction function but the priority of monetary policy for controlling the real exchange rate comes only after the stabilizing inflation and the output gap.

Alternative specification

The LSTAR and QL-STAR models as given by Eq. (3.9) and (3.10) assume that the lag dependent is unaffected by the inflation regime. And, the estimates, so far, show that interest rate is highly persistence ($\rho \cong 0.9$). The main aim of these alternative estimates is, therefore, to test whether interest rate persistence is same in both regimes and whether this specification alters our main findings.

We now relax the assumption of a single smoothing parameter and allow the lag dependent variable, i_{t-1}, to both regimes in Eq. (3.9) and (3.10). Therefore, we have two smoothing parameters (k_{10} and k_{20}) in the alternative specification in both LSTAR and QL-STAR models as an alternative of single smoothing parameter (ρ) earlier. The detailed specification of the model is given in Appendix 3.1.

The estimates of the alternative specification are presented in Appendix 3.2 where the second column gives the estimate of the LSTAR model whereas the last column presents the estimate of the QL-STAR model. We estimate the threshold parameter τ = -0.370% (implies inflation threshold to be 2.13%) using the alternative LSTAR model which is slightly lower than that of the main estimate. Similarly, we estimate $\tau^{L} = -1.089\%$ and $\tau^{U} = 0.728\%$ employing the alternative QL-STAR model where the lower threshold is almost same to the main estimate but the upper threshold is slightly higher.

Most importantly, we do not reject the null hypothesis that $H_0 : k_{10} = k_{20}$ against $H_1 : k_{10} \neq k_{20}$ in both models. This implies that the interest rate persistence is not affected by the inflation regime.

3.5 Conclusion

This chapter models the monetary policy for UK for the ongoing inflation targeting era using both the linear and variety of nonlinear monetary policy reaction functions. The main contributions of this chapter are the empirical findings that

(a) Monetary policy in UK responds to asset prices together with deviations of inflation from the target and the output gap.

(b) The monetary policy rule is nonlinear and policy response is asymmetric. Moreover, the policy response to inflation is more vigorous when expected inflation is not close to the target. On the other hand policy does not respond to inflation when expected inflation is close to the target,

(c) The policy response to the output gap and RER misalignment also depends on the inflation regime. The response to the output gap and the RER misalignment becomes relatively stronger when the economy is in the inner inflation regime compared to a sluggish response when the economy is in the outer inflation regime,

(d) Interest rate persistence is found to be high, around 0.9. This is not affected by the inflation regime, and finally,

(e) Policymakers are attempting to keep the inflation within a band of 1.42% - 2.87% rather than attempting to hit a target of 2.5%.

Our work could be extended in different ways. First, it would be interesting to include house prices and share prices in nonlinear estimates as these variables are found to be significant in the linear estimates.

Second, our model assumes that inflation is the only source of nonlinearity. In practice, however, nonlinearity may arise due to the output gap and RER misalignment. Therefore, it would be interesting to estimate nonlinear models allowing regimes for the output gap and the RER misalignment.

Third, although this chapter does not acknowledge the role of the foreign interest rates in the conduct of monetary policy, this variable might be important in practice, especially, in an open economy.

Fourth, we assumed that policy response to inflation is same between a high inflation and a low inflation period as the outer regime combines both of them. This assumption may not be true in practice. We address these issues in the following chapters.

Chapter 4

Nonlinear and Asymmetric Monetary policy in UK: Evidence from the open economy Taylor rule

4.1 Introduction

The Bank of England (BoE) has been targeting inflation since October 1992. The objective was to keep inflation within a range of 1%-4% over the period of Oct 1992 to April 1997 though a medium term target of 2.5% was also announced in June 1995. The target range was abolished in May 1997 and introduced an explicit point target of 2.5%. Since then, the bank is required to give a formal explanation to the government in case if inflation deviates for more than 1% in either direction from the target (Bernanke et al., 1999). It implies that a high inflation and a low inflation are equally bad for monetary policy. But does the BoE consider a low and a high inflation equally bad in practice?

In the previous chapter we found that policy does not respond to inflation when expected inflation is close to the target. We also found that the BoE has been attempting to keep inflation within a range rather than hitting a point target in practice. But it does not describe the issue we raised. This chapter, therefore, extends the previous chapter in two different ways.

First, although we estimated various nonlinear models in chapter 3, the conclusion was mainly based on the estimate of the quadratic logistic smooth transition autoregressive (QL-STAR) model. One of the limitations of this model is that it provides only two regimes, the inner and outer, where the outer regime combines the lower and the upper regime. This chapter, therefore, seeks to analyze whether policy response to large negative deviations and large positive deviations of inflation from the target is the same. To do so, we use a three-regime smooth transition autoregressive (STAR) model which provides lower, inner and upper inflation regimes.

Second, the previous chapter addressed the issue of the open economy by estimating an exchange rate augmented Taylor rule. The literature, however, argues that monetary policy also responds to the foreign interest rate. There are at least two strands of literature that finds an active role of the foreign interest rate in the conduct of domestic monetary policy.

Firstly, many empirical studies assess the relevance of the foreign interest rates by including them in a Taylor rule. For instance, Adam et al. (2005), Angeloni and Dedola (1999), among others, find that UK monetary policy responds to the US and German interest rates together with the output gap and inflation. They argue that the BoE is more concerned with the foreign interest rates than with the real exchange rate.

Secondly, there is a vast amount of literature related to purchasing power parity, interest rates convergence and the interest rate volatility, which overwhelmingly suggest that the interest rates across the countries converge in the long run. More specifically, the literature argues that the US world-wide dominance hypothesis in general and the German lead hypothesis in particular for the case of European countries hold, meaning other countries around the globe just follow the interest rate movements of these two countries. The contribution of Caporale et al. 1996, Awad et al. 1998; Barassi et al., 2003; Homes and Marghrebi, 2005, among others; show that the UK is not the exception of this tradition[33]. The convergence of the domestic short term interest rates to the foreign interest rates implies that monetary policy responds to the foreign interest rate.

[33] A detailed discussion of this class of literature is beyond the scope of this chapter.

Therefore, taking these two issues into account, this chapter mainly estimates the foreign interest rate augmented Taylor rule using a three regime smooth transition autoregressive model for the ongoing inflation targeting regime in UK. The empirical estimates provide ample evidences that the aim of monetary policy is to keep inflation within a range rather than pursuing a point target of 2.5%. We find that the monetary policy in UK has a deflationary bias as it does not respond to inflation when the expected inflation is below the lower band, respond mildly when it is within the bands and reacts more vigorously when it exceeds the upper band. By contrast, the policy response to the output gap is stronger when economy is in the lower inflation regime compared to a sluggish response when it is in the inner or upper regimes. We also find that the policy reaction to the foreign interest rate is not affected by the inflation regime.

The structure of the rest of this chapter is as follows. Section 4.2 presents the methodology followed by the description of data in section 4.3. Section 4.4 delivers the empirical results. Section 4.5 provides classification of observations over inflation regimes followed by impact analysis in section 4.6. Section 4.7 provides some robustness analysis. Finally, section 4.8 concludes the chapter.

4.2 Methodology

4.2.1 Linear reaction function

Following Clarida et al. (1998, 2000) and Adam et al. (2005), among others, we first consider the foreign interest rate augmented linear Taylor rule.

$$i_t^* = \bar{i}^* + c_\pi(E_{t-1}\pi_{t+j} \mid \Omega_t - \pi^T) + c_y[E_{t-1}(y_{t+k} - y_{t+k}^P) \mid \Omega_t] + c_{if} i_t^f \qquad (4.1)$$

Where, $\bar{i}^*$ is the desired nominal interest rate when both inflation and output are at their target levels; Ω_t is the information set available to policymakers while setting interest rates at time t; E_{t-1} is the expectation formed at t given the information of t-1. $E_{t-1}\pi_{t+j} \mid \Omega_t$ is the expected inflation at time t for t+j, π^T is the targeted rate of inflation; $E_{t-1}(y_{t+k} - y_{t+k}^P) \mid \Omega_t$ is the expected output gap at time t for t+k; and i_t^f is the foreign interest rate at time t.

Eq. (4.1) is a forward looking open economy Taylor rule in which the desired short term nominal interest rate, i_t^*, is determined by the combination of expected deviations of inflation from the target, $E_{t-1}\pi_{t+j} \mid \Omega_t - \pi^T$, the expected output gap, $E_{t-1}(y_{t+k} - y_{t+k}^P) \mid \Omega_t$, and the foreign interest rate, i_t^f. The interpretation of the model is straightforward. The central bank aims to stabilize inflation if the parameter $c_\pi > 1$ while a destabilizing policy takes place otherwise. A similar logic applies to the output gap and to the foreign interest rates. We expect c_y>0 if the policy stabilizes the output gap. We expect c_{if} >0 if policy responds to the foreign interest rates (Clarida et al., 2000 and Chadha et. al., 2004).

Eq. (4.1) provides a policy framework where the authority attempts to attain the desire rate all the time, which may be needed a frequent policy reversal in response to deviations of inflation from the target and the output gap. This approach to monetary policy is not desirable in practice. It is argued that a good monetary policy should not be reversed frequently in order to assure the private sector confidence in the economy and also to minimize any adverse effects of policy changes in the capital market[34]. For this reasons, we assume that the central bank operates smoothing changes in the interest rates rather than adopting an immediate reactive type of policy measures (Clarida et al. 2000). This type of policy behavior can be summarized as[35]:

$$i_t = \rho i_{t-1} + (1-\rho) i_t^* + v_t \qquad v_t \sim iid(0, \sigma^2) \tag{4.2}$$

Eq. (4.2) states that the observed interest rate, i_t, is the weighted average of a desired rate, i_t^*, and the previous period rate, where $\rho \in (0,1)$ is the smoothing parameter

[34] Detailed discussions can be found in Goodfriend (1987) and Clarida et al. (1998 and 2000), among others.

[35] We assumed the first order partial autocorrelation function but a higher order is also possible (Calrida et al. 1998)

which determines the degree of policy change. A higher value of ρ implies that policy response takes place more gradually.

When combining Eq. (4.1) and Eq. (4.2) yields

$$i_t = \bar{i} + \rho i_{t-1} + (1-\rho)[c_\pi E_{t-1}(\pi_{t+j} - \pi^T) + c_y E_{t-1}(y_{t+k} - y^P_{t+k}) + c_{if} i^f_t] + \varepsilon_t \qquad (4.3)$$

Eq. (4.3) is the final estimable linear reaction function where $\bar{i}$ the equilibrium interest rate and ε_t is the sum of a linear combination of a pure stochastic errors and forecast errors of inflation and the output gap, conditional on their information set, Ω_t, at time t where ε_t is assumed to be orthogonal to Ω_t (see Clarida et al., 2000 and Chadha et al. 2004 for the detail discussion).

There is a consensus in the literature that policymakers consider at least up to four quarter lags of interest rates, inflation, and the output gap as information set, Ω_t, while taking monetary policy decision. Therefore, testing the orthogonality condition in Eq. (4.3) surely implies a test of over identifying restriction as the total number of instruments exceed the total number parameters to be estimated (Newey and West, 1987 and Davidson and Mackinnon, 1993). The null hypothesis may be defined as the over identifying restriction is satisfied in which case accepting the null implies that central banks adjust interest rates in each period so that Eq. (4.3) holds; the model is mis-specified otherwise.

4.2.2 Nonlinear reaction function

Based on the benchmark linear reaction function as given by Eq. (4.3), we now formulate a nonlinear monetary policy reaction function using the three regime smooth transition autoregressive model[36] (van Dijk et. al., 2002).

$$i_t = i^* + \rho i_{t-1} + (1-\rho)[M_{Lt}\theta_{Lt} + M_{It}\theta_{It} + M_{Ut}(1-\theta_{Lt}-\theta_{It})] + \varepsilon_t \qquad \varepsilon_t \sim iid(0,\sigma^2) \quad (4.4)$$

Where,

$$\theta_{Lt} = \Pr\{(\pi_{t+d} - \pi^T) < \tau^L\} = 1 - [1 + \exp\{-\gamma(\pi_{t+d} - \pi^T + \tau^L)/\sigma_\pi\}]^{-1} \quad (4.5)$$

$$\begin{aligned}\theta_{It} &= \Pr\{\tau^L \le (\pi_{t+d} - \pi^T) \le \tau^U\} \\ &= 1 - [1 + \exp\{-\delta(\pi_{t+d} - \pi^T + \tau^L)(\pi_{t+d} - \pi^T - \tau^U)/\sigma_\pi^2\}]^{-1} \quad (4.6)\end{aligned}$$

$$M_{Lt} = c_{11}E_{t-1}(\pi_{t+j} - \pi^T) + c_{12}E_{t-1}(y_{t+k} - y_{t+k}^P) + c_{13}i_t^f \quad (4.7)$$

$$M_{It} = c_{21}E_{t-1}(\pi_{t+j} - \pi^T) + c_{22}E_{t-1}(y_{t+k} - y_{t+k}^P) + c_{23}i_t^f \quad (4.8)$$

$$M_{Ut} = c_{31}E_{t-1}(\pi_{t+j} - \pi^T) + c_{32}E_{t-1}(y_{t+k} - y_{t+n}^P) + c_{33}i_t^f \quad (4.9)$$

$$\gamma > 0,\ \delta > 0 \text{ and } \tau^L < \tau^U$$

Eq. (4.4) states that i_t is a weighted average of the "lower regime", M_{Lt}, the "inner regime", M_{It}, and the "upper regime" ,M_{Ut} where θ_{Lt}, θ_{It} and $(1-\theta_{Lt}-\theta_{It})$ are

[36] See Chapter 5 for the detailed discussion.

corresponding regime weights. In this model, inflation regimes are classified by the lower threshold, τ^{L}, and the upper threshold, τ^{U}.

More specifically, θ_{Lt} is the probability that expected inflation is less than the lower threshold [$(\pi_{t+d} - \pi^{T}) < \tau^{L}$] whilst θ_{It} is another probability that it is between two thresholds [$\tau^{L} \leq (\pi_{t+d} - \pi^{T}) \leq \tau^{U}$]. This implies $(1 - \theta_{Lt} - \theta_{It})$ is the probability that expected inflation exceeds the upper threshold [$(\pi_{t+d} - \pi^{T}) > \tau^{U}$] where d is the time horizon of the transition variable, often known as the "delay parameter".

Eq. (4.7), (4.8) and (4.9) are augmented Taylor rules as similar to Eq. (4.1). The interest rate is solely determined by Eq. (4.7), that is M_{Lt}, when $(\pi_{t+d} - \pi^{T}) < \tau^{L}$ while it determines by Eq. (4.9), that is M_{Ut}, when $(\pi_{t+d} - \pi^{T}) > \tau^{U}$. Policymakers set interest rate based on Eq. (4.8), i.e. M_{It}, when $\tau^{L} \leq (\pi_{t+d} - \pi^{T}) \leq \tau^{U}$.

Equation (4.5) is a logistic function that allows for symmetric adjustments to positive and negative deviations of transition variable, $\pi_{t+d} - \pi^{T}$, relative to τ^{L} where θ_{Lt} changes monotonically from 0 to 1 as $\pi_{t+d} - \pi^{T}$ increases. The slope parameter, γ, determines the smoothness of changes in the value of θ_{Lt}. When $\gamma \to 0$, θ_{Lt} becomes a constant and when $\gamma \to +\infty$, the transition from $\theta_{Lt}=0$ to $\theta_{Lt}=1$ becomes instantaneous at $\pi_{t+d} - \pi^T = \tau^L$. Following Granger and Terasvirta (1993) and Terasvirta (1994) we make γ dimension free by dividing it by the standard deviation of π_t.

Equation (4.6) is a quadratic logistic function, which gives the probability that $\tau^L \leq (\pi_{t+d} - \pi^T) \leq \tau^U$. This function has two important properties: (a) θ_{lt} becomes constant as $\delta \to 0$ and (b) as $\delta \to \infty$, θ_{lt}=1 if $\tau^L \leq (\pi_{t+d} - \pi^T) \leq \tau^U$ and θ_{lt}=0 if $(\pi_{t+d} - \pi^T) < \tau^L$ or $(\pi_{t+d} - \pi^T) > \tau^U$. Following Granger and Terasvirta (1993), δ is made dimension free by dividing it by the variance of π_t.

The nonlinear reaction function, Eq. (4.4) simplifies to the linear reaction function in (4.3) if H_{01}: $c_{1i} = c_{2i} = c_{3i}$ for all i={1 to 3} (Luukkonen et al., 1988, Terasvirta, 1994 and van Dijk et. al., 2002). Similarly, the model simplifies to the two regime quadratic logistic smooth transition autoregressive model in Eq. (3.10) of Chapter 3 if H_{02}: $c_{11} = c_{12} = c_{13} = 0$ or if $H_{02} : \gamma = 0$. Finally, the model simplifies to the two regime logistic smooth transition autoregressive model in Eq. (3.9) of Chapter 3 if H_{03}: $c_{21} = c_{22} = c_{23} = 0$.

In this model, we assess whether the policy response to inflation is symmetric by testing a null hypothesis $H_{04}:[(\pi^T - \tau^L) + (\pi^T + \tau^U)]/2 = 2.5\%$ against an alternative hypothesis $H_{14}:[(\pi^T - \tau^L) + (\pi^T + \tau^U)]/2 \neq 2.5\%$. Rejecting the null implies that the policy is asymmetric.

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4.3 The data

Similar to chapter 3 and 5 but with a more expanded sample, we use quarterly data for UK over the period of 1992Q4 to 2005Q4. The three month Treasury Bill rate is used as a measure of the short term interest rate, i_t, and the year-on-year change in the retail price index (RPI) as a measure of inflation, π_t. The targeted rate of inflation, π^T, is assumed to be 2.5%.

We use real GDP as a measure of output, y_t, and obtain potential output, y_t^P, using the Hodrick-Prescott (1997) de-trending technique. The output gap is then computed as the difference between the actual and potential output, $y_t - y_t^P$. Finally, the US Federal fund rate is employed as a measure of the foreign nominal interest rate, i_t^f.

The data is obtained from the IFS collected by DataStream. The statistical properties of variables are available in Chapter 3 and 5. Figure 4.1 and 4.2 provide the plots of variables.

Figure 4.1: Domestic and foreign nominal interest rates (1992Q4-2005Q4)

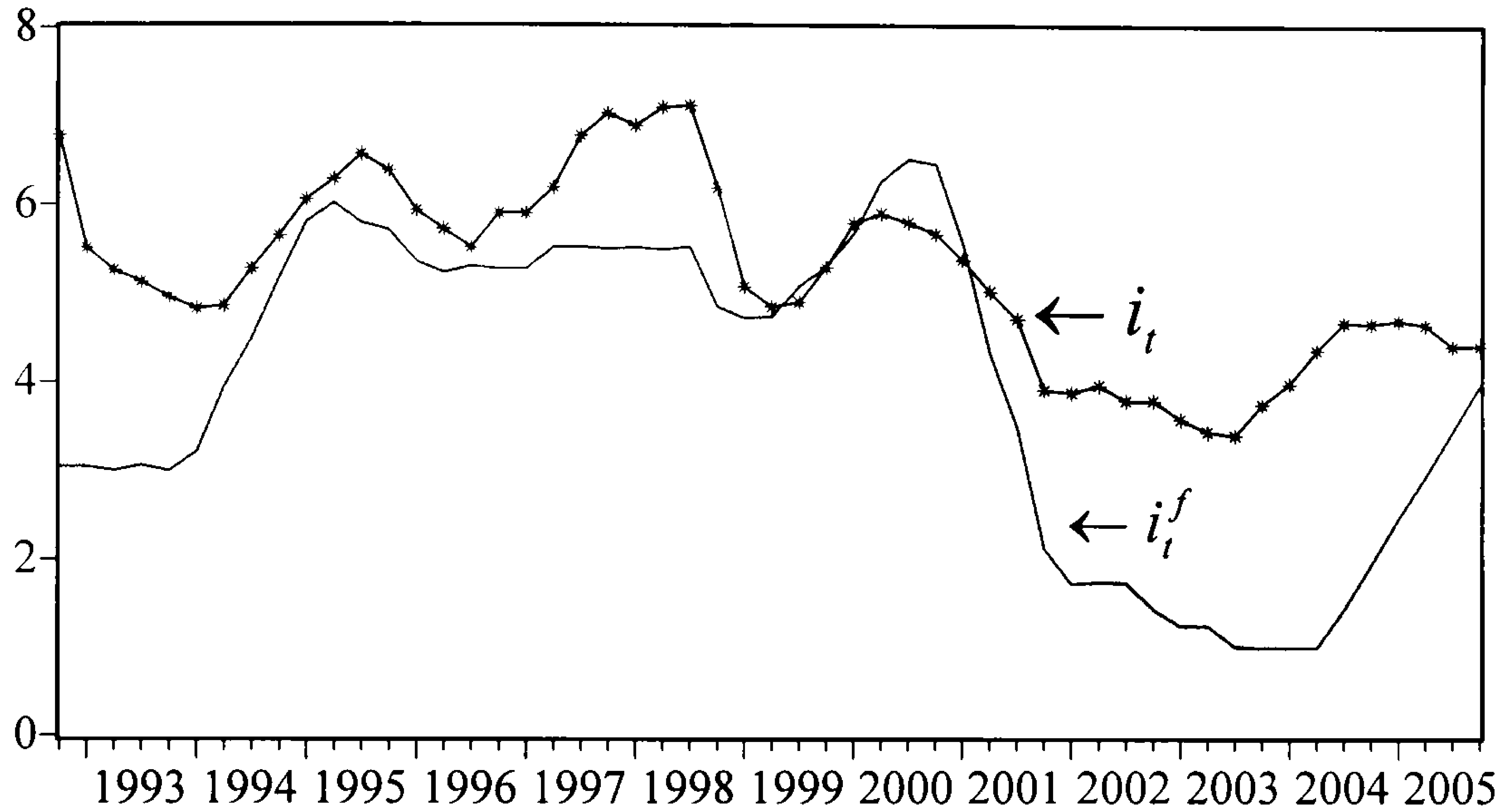
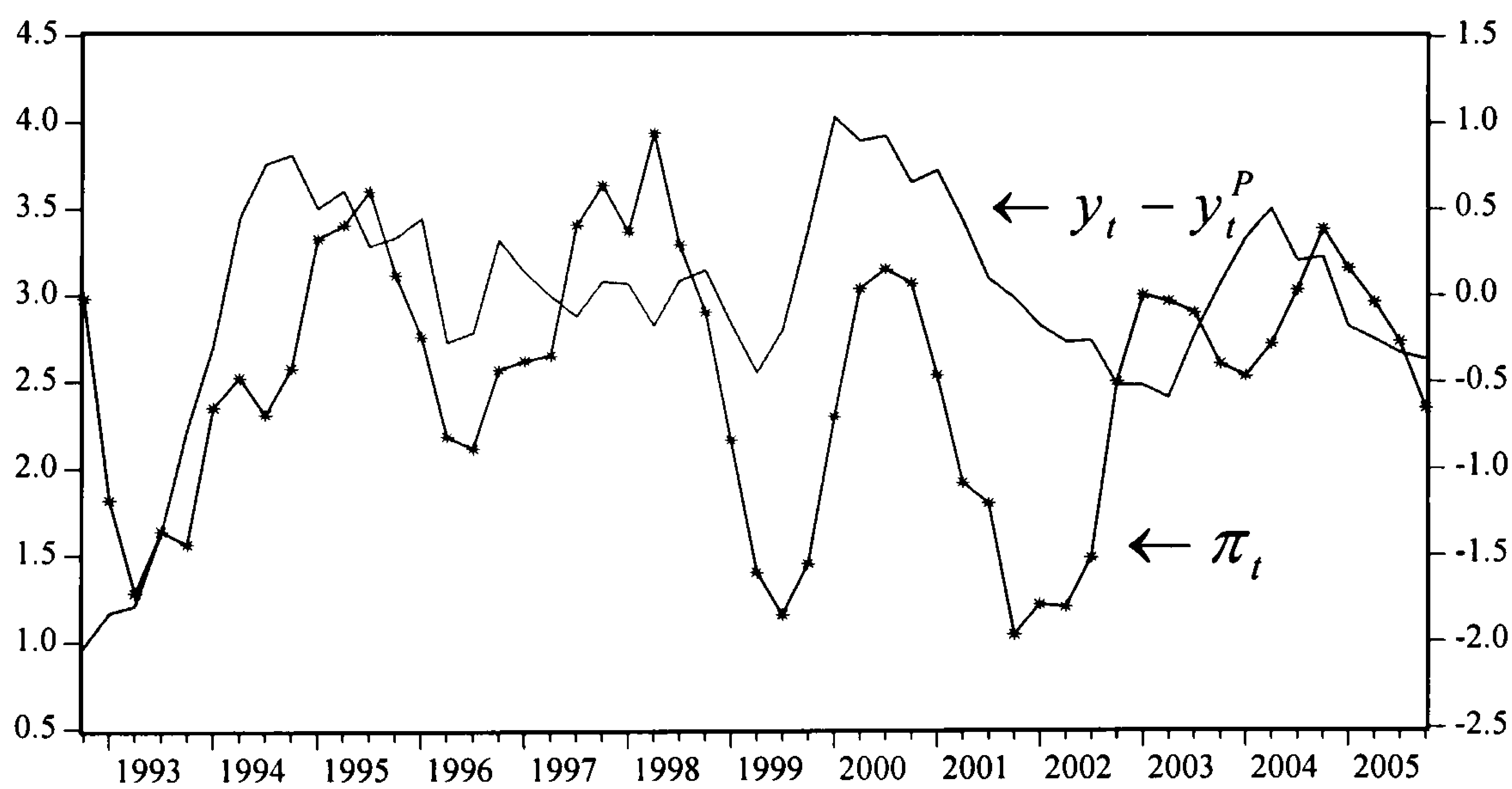


Figure 4.2: Inflation and the output gap (1992Q4 – 2005Q4)



Note: the left vertical axis measures the inflation and the right axis measure the output gap.

4.4. Empirical results and discussion

Our initial experiments suggest that a one-period-ahead forward looking augmented Taylor rule provides the best estimate of Eq. 4.3. This is consistent with the literature (Adam et al. 2005, Nelson, 2000, Martin and Milas, 2004). Therefore, unless otherwise stated, we use j=k=1 and l=0 as the time horizons of variables for all reported estimates.

Column (i) of Table 4.1 provides estimates of the linear reaction function, i.e. Eq. (4.3). A constant and up to five lags of interest rates, inflation and the output gap are used as instrument set for the estimate. In this estimate, the parameters are correctly signed and are significant at 1% and the overidentifying restriction is also satisfied. Moreover, the dynamic stability criterion is fulfilled as we find ρ_{π}>1 (Martin and Milas, 2004, Clarida et. al., 1998 and Adam et. al. 2005) obtaining the size of parameters as $\rho_{\pi} > \rho_{y} > \rho_{if}$, suggesting that policy reaction to inflation is more vigorous followed by the output gap and then the foreign interest rate.

Table 4.1: Linear and nonlinear GMM estimates (1992Q4 – 2005Q4)

Parameters\models	Linear Estimate$^{\Psi}$ (i)	Unrestricted Nonlinear estimate$^{\varphi}$ (ii)	Restricted nonlinear estimate$^{\varphi}$ (iii)
i^*	0.635 (0.187)*	0.783 (0.090)*	0.679 (0.089)*
ρ	0.758 (0.057)*	0.740 (0.025)*	0.799 (0.024)*
c_π or c_{11}	1.609 (0.413)*	0.951 (0.613)	
c_y or c_{12}	1.074 (0.449)**	1.714 (0.405)*	2.111 (0.382)*
c_{if} or c_{13}	0.426 (0.045)*	0.295 (0.085)*	0.221 (0.057)*
c_{21}		1.150 (0.216)*	1.512 (0.282)*
c_{22}		1.852 (0.337)*	1.447 (0.344)*
c_{23}		0.318 (0.046)*	0.221 (0.057)*
c_{31}		2.257 (0.188)*	2.203 (0.306)*
c_{32}		1.786 (0.228)*	1.447 (0.344)*
c_{33}		0.270 (0.028)*	0.221 (0.057)*
γ		33.978 (43.53)	33.978 (43.53)
δ		366.019 (243.43)	366.019(243.43)
τ^L		-0.859 (0.150)*	-0.859 (0.150)*
τ^U		0.314 (0.025)*	0.314 (0.025)*
$\overline{R}^2$	0.872	0.895	0.923
Standard error	0.367	0.332	0.281
Normality	0.082 [0.959]	4.881 [0.111]	3.022 [0.221]
J-statistics {p_value}	0.534 {0.971}	0.215 {0.875}	0.243 {0.891}
Hypothesis Tests			

$H_{01}: c_{1i} = c_{2i} = c_{3i} (i = 1,2,3)$		13.763 [0.000]	
$H_{02}: c_{11} = c_{12} = c_{13} = 0$		15.943 [0.000]	
$H_{03}: c_{21} = c_{22} = c_{23} = 0$		43.353 [0.000]	
$H_{04}: [(\pi^T - \tau^L) + (\pi^T + \tau^U)]/2 = 2.5\%$		17.509 [0.000]	
$H_{05}: \pi^T - \hat{\tau}^L = 1.5\%$		2.154 [0.161]	
$H_{06}: \pi^T + \hat{\tau}^U = 3.5\%$		54.106 [0.00]	
$H_{07}: c_{21} = c_{31}$		10.533 [0.000]	
$H_{08}: c_{22} = c_{32}$		0.453 [0.593]	
$H_{09}: c_{13} = c_{23} = c_{33}$		13.763 [0.200]	

Note:

(a) *Superscripts* $^{\psi}$ *and* $^{\varphi}$ *indicate the estimate of Eq. (4.3) and Eq. (4.4) respectively.*

(b) *The interest rate, deviations of inflation from the target and the output gap are considered to be endogenous variables.*

(c) *j=k=1 and l=0 is used as time horizon of variables for all estimates.*

(d) *(.) are standard errors, [.] are probability values of the test statistics and {.} are probability values of the test that the over identified restriction is satisfied under null.*

(e) *Normality is the F-test for normality. J-statistics is the value of the GMM objective function.*

(f) *A constant and up to 5 lags of all variables are used as instrument set for estimates.*

(g) ** and ** indicate significant at 1% and 5% respectively.*

(h) *Three restrictions are imposed in column (iii):* $c_{11} = 0$, $c_{22} = c_{32}$, *and* $c_{13} = c_{23} = c_{33}$.

As discussed, the linear estimate does not offer all the issues raised in the beginning of this chapter even though the estimate is robust. We, therefore, estimate the nonlinear reaction function, Eq. (4.4). The estimation procedure closely follows the work of van-Dijk and Franses (1999), Madsen and Milas (2005) and Arghyrou et al. (2005). To start with, we use the estimated parameters of the linear reaction function as the initial values for all augmented Taylor rules in Eq. (4.4); fix the time horizon of variables similar to the linear estimate (j=k=1 and l=0); and conduct a grid-search for thresholds, slope and the delay parameter to arrive at the best possible estimate.

Column (ii) of Table 4.1 reports the estimate of Eq. (4.4) using one period ahead expected deviations of inflation from the target as transition variable[37], $\pi_{t+1} - \pi^T$, which produces relatively a better result than any other specification. We do not reject the overidentifying restriction, suggesting that the instrument set is orthogonal to the error term. Clearly, the nonlinear estimate outperforms the linear estimate in various ways[38]. The standard error has reduced significantly in the nonlinear model compared to the linear one. The linearity test rejects the linear model as H_{01} is rejected. Also,

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[37] We experiment various leads and lags as a candidate of the delay parameter but find a better result using d=1. Chapter 3 provides more discussion about this.

[38] Although the slope parameters (γ and δ) are found to be insignificant, it is not an evidence of weak nonlinearity. It is because an accurate estimate of these parameters is not possible if the sample size is relatively small like we have (see Terasvirta 1994, Van Dijk et al., 2002, and Lekkos et al., 2006 for more discussion).

the three regime model can not be simplified either to the QLSTAR model in Eq. (3.10) or LSTAR model in Eq. (3.9) because we decisively reject H_{02} and H_{03}.

We obtain a number of interesting findings from this estimate. First, we estimate regime boundaries to be τ^L = -0.859% and τ^U = 0.314% and find both of them to be significant at 1%. This implies that the UK monetary policymakers consider three distinct inflation regimes for the policy purpose in practice. The economy is in the lower inflation regime when $\pi_{t+1} - \pi^T < -0.859\%$ (i.e. $\pi_{t+1} < 1.641\%$ as we have π^T=2.5%) and in the upper inflation regime when $\pi_{t+1} - \pi^T > 0.314\%$ (i.e. $\pi_{t+1} > 2.81\%$). The economy is in the inner inflation regime when $1.64\% \le \pi_{t+1} \le 2.81\%$.

Second, we reject the null hypothesis, $H_{04} : [(\pi^T - \tau^L) + (\pi^T + \tau^U)]/2 = 2.5\%$ at 1%, suggesting that monetary policy in UK is asymmetric. As the BoE has to give a formal explanation to the government if inflation exceeds 3.5% or falls below 1.5%, we test whether the estimated lower boundary is equivalent to 1.5%, i.e. $H_{05} : \pi^T - \hat{\tau}^L = 1.5\%$, and the upper boundary is equivalent to 3.5%, i.e., $H_{06} : \pi^T + \hat{\tau}^U = 3.5\%$. Interestingly, we do not reject H_{05} but strongly reject H_{06}. The estimates of thresholds and their symmetric tests, therefore, indicate that policymakers are more conscious with positive deviations of expected inflation from the target compared to the negative ones.

Third, we find that c_{11} is insignificant but c_{21} and c_{31} are significant at 1% with $c_{31} > c_{11}$. Further we strongly reject the null hypothesis that $H_{07} : c_{21} = c_{31}$. This all implies that monetary policy has a deflationary bias because it does not respond to inflation when expected inflation is less than the lower threshold[39] ($\pi_{t+1} < 1.64$). But it responds to inflation vigorously when expected inflation exceeds the upper threshold ($\pi_{t+1} > 2.81$). The reaction to inflation is mild when expected inflation remains in the inner regime ($1.64 \le \pi_{t+1} \le 2.81$).

Fourth, we observe that policy reaction to the output gap depends on the inflation regime. The response to the output gap is stronger in the lower inflation regime compared to responses in other two regimes. Further, we find that policy response to the output gap between the inner and upper inflation regime does not vary because we estimate $c_{22} = 1.85$, $c_{32} = 1.77$ and do not reject a null hypothesis that they are equal, i.e. $H_{08} : c_{22} = c_{32}$.

Finally, we find that policy response to the foreign interest rate is mild but is unaffected by the inflation regimes. We estimate $c_{13} = 0.30$, $c_{23} = 0.32$, and

[39] The finding however should be taken cautiously because there are only 9 observations in the lower regime.

$c_{33} = 0.27$ but do not reject the null hypothesis that they are equal, i.e. $H_{09} : c_{13} = c_{23} = c_{33}$.

Based on hypotheses tests, we estimate a more restrictive version of Eq. 4.4 by imposing three restrictions on the parameter estimates. They are c_{11}=0, $c_{22} = c_{32}$ and $c_{13} = c_{23} = c_{33}$. Column (iii) of Table 4.1 presents the empirical results, which are our preferred estimates because this estimate provides the smallest standard error than any other estimates and the parameters are correctly signed and significant.

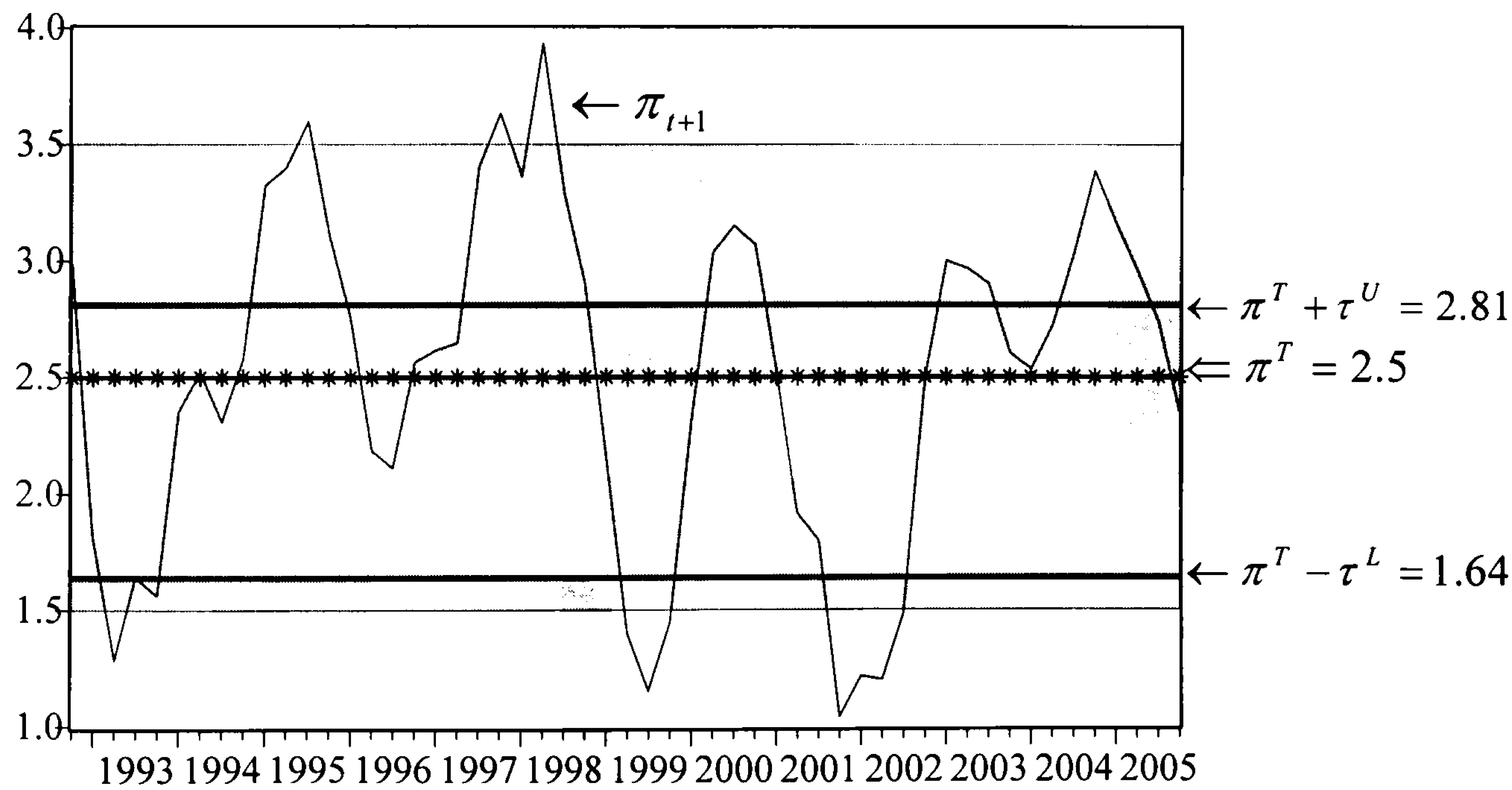
4.5. Classification of observations

Figure 4.3 provides a plot of two thresholds, expected inflation, targeted rate of inflation and the "target zone" together. The estimated two thresholds ($\pi^T - \tau^L =$ 1.64% and $\pi^T + \tau^U =$ 2.81%) provide three regimes: the lower, inner and the upper regimes. The target rate ($\pi^T = 2.5\%$) is obviously plotted between the upper and the lower inflation thresholds. Finally, the shaded area in between 1.5% and 3.5% is defined as the "target zone" because the BoE does not have to give any explanation to the government if inflation remains within this area.

There are 9 quarters out of total 53 in our sample period (late 1993, 99Q2-Q4 and 01Q4-02Q3) when expected inflation was below the lower threshold (1.64%). There are five episodes (1995, 97Q3-98Q4, 2000, 2003, 04Q3-05Q3) when inflation exceeded the upper threshold and expected inflation was maintained within our estimated bands of 1.64% to 2.81% in other periods.

When observing the "target zone", we find that inflation never crossed the upper boundary of 3.5% except for three quick jumps in the 1990s when the exchange rate was appreciated. On the other hand, there are three small episodes in early inflation targeting period, in 1999 and 2001 when inflation fell below 1.5% for which the movement of asset prices in general and the fall in house prices in particular is blamed.

Figure 4.3: Inflation and thresholds (1992Q4 – 2005Q4)



4.6. Impact analysis

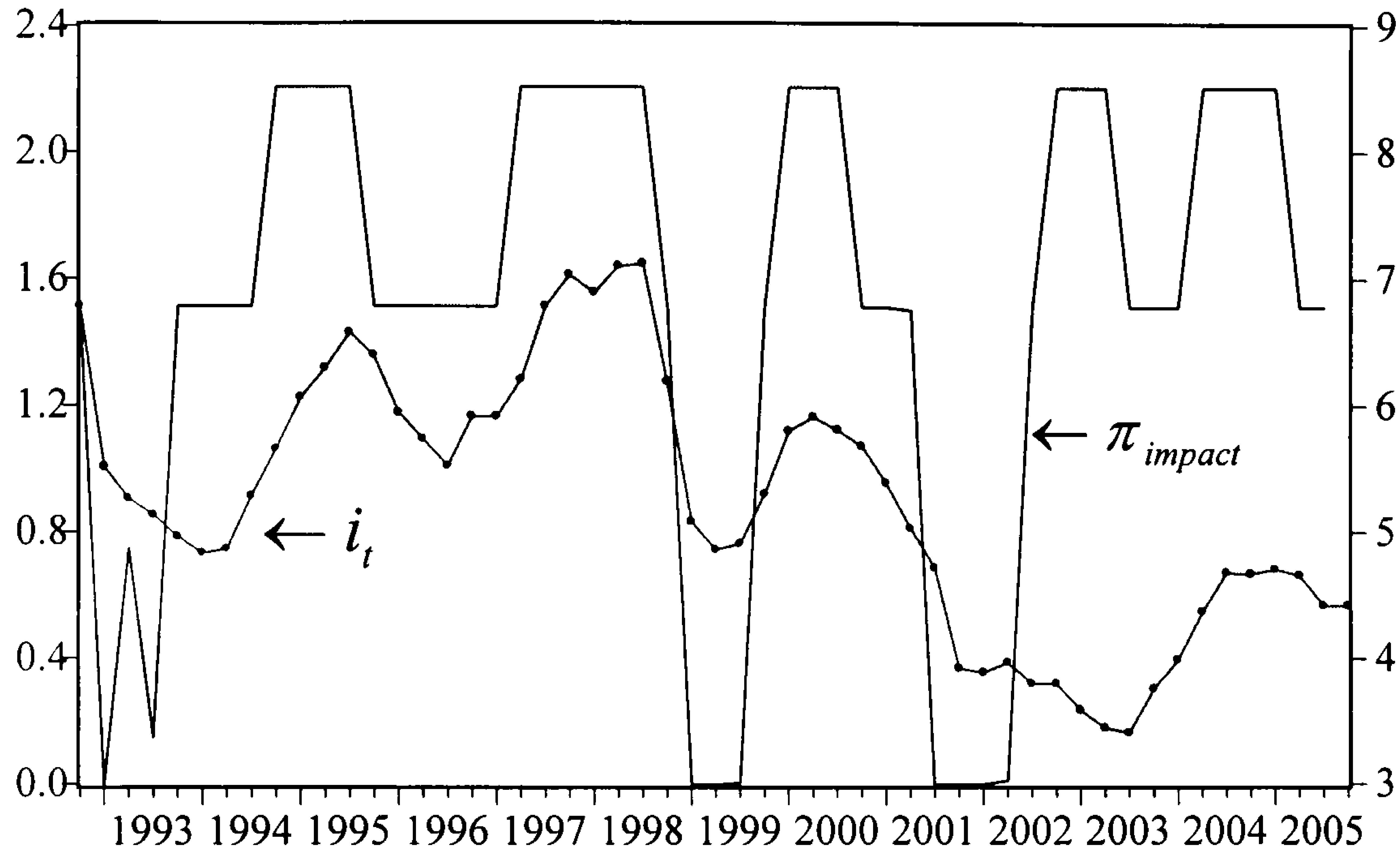
The linear model as given by Eq. (4.3) has a constant impact on the interest rate irrespective to the positive/negative or big/small deviations of inflation from the target. The estimate shows that 1% increase in the deviation of inflation from the target increases the interest rates by 1.6%.

The impact analysis in nonlinear reaction function is not straightforward. We obtain nonlinear impacts using the formula given below (Martin and Milas, 2004 and Arghyrou et al., 2005)

$$\pi_{impact} = c_{11}\phi_{Lt} + c_{21}\theta_{It} + c_{31}(1-\phi_{Lt}-\theta_{It}) \tag{4.10}$$

Figure 4.4 plots the nonlinear impact of deviations of inflation from the target on the interest rate. We clearly observe that the interest rate has decreased in a period when expected inflation was below the lower threshold while it increased when expected inflation exceeded the upper band in most of the period. We, therefore, argue that our nonlinear model has been able to describe the behavior of UK monetary policy more accurately.

Figure 4.4: The nonlinear impact of inflation on interest rate (1992Q4-2005Q4)



Note: a. $\pi_{impact} = c_{11}\phi_{Lt} + c_{21}\theta_{It} + c_{31}(1-\phi_{Lt}-\theta_{It})$

b. The left vertical axis measures π_{impact} *and the right vertical axis measure* i_t

4.7. Robustness analysis

Although the linear and nonlinear estimates discussed above are the best among various experiments, we report some of the alternative nonlinear specifications to give more insights of the policy behaviour.

Table 4.2: Alternative nonlinear specifications: GMM estimates

(1992Q4 – 2005Q4)

Estimates	(i)	(ii)	(iii)
i^*	0.349 (0.053)*	0.750 (0.068)*	0.683 (0.150)*
ρ	0.880 (0.010)*	0.827 (0.021)*	0.822 (0.052)*
c_{12}	3.726 (0.707)*	3.916 (1.118)*	2.171 (1.097)*
c_{13}	0.299 (0.054)*	0.185 (0.061)*	0.285 (0.118)*
c_{21}	2.045 (0.311)*	1.293 (0.202)*	1.464 (0.869)*
c_{22}	2.659 (0.252)*	1.472 (0.396)*	1.141 (0.636)*
c_{23}	0.299 (0.054)*	0.185 (0.061)*	0.285 (0.118)*
c_{31}	2.854 (0.327)*	2.735 (0.573)*	2.620 (0.394)*
c_{32}	2.659 (0.252)*	1.472 (0.396)*	1.141 (0.636)*
c_{33}	0.299 (0.054)*	0.185 (0.061)*	0.285 (0.118)*
γ	33.978 (43.533)	33.978 (43.533)	120.450(80.432)
δ	366.019(243.434)	366.019(243.434)	79.819 (220.32)
τ^L	-0.859 (0.150)*	-0.859 (0.150)*	-0.739 (0.150)*
τ^U	0.314 (0.025)*	0.314 (0.025)*	0.200 (0.059)*
$\overline{R}^2$	0.896	0.909	0.920
Standard error	0.330	0.308	0.289
Normality	3.871 [0.183]	0.634 [0.598]	2.673 [0.291]
J-statistics	0.223	0.246	0.415
p-value	0.984	0.921	0.977

Note:

(a) column (i) uses the European money market rate as an alternative to the Federal fund rate. Column (ii) uses j=k=2 as time horizon of inflation and output gap

instead of j=k=1 earlier. Column (iii) employ $\pi_{t-1} - \pi^T$ *as transition variable as an alternative to* $\pi_{t+1} - \pi^T$.

(b) *Column (i) and (ii) imposes the same thresholds and slope parameters which are presented in column (ii) of Table 4.1*

(c) *See the footnotes of Table 4.1 for other explanations.*

First, we use the European money market rate as an alternative to the US interest rate in Eq. (4.4). The estimate is reported in column (i) of Table 4.2 where we imposed the same threshold and slope parameters as before. Using this variable does not alter our main findings.

Second, the literature also argues that the BoE has a target horizon up to one year ahead (Chadha et al., 2004 and Adam et al., 2005 for example). We, therefore, attempt to estimate Eq. (4.4) using the same thresholds and slope parameters but altering the time horizon of expected inflation and the output gap up to four quarter ahead. As we find more or less similar results from all experiments, we report the estimate of two period ahead target horizons of inflation and output gap (j=k=2 and l=0) as an alternative to one period ahead in Column (ii) of Table 4.2. Notice that this estimate also carries the same thresholds and slope parameters as estimated before.

We also experiment various delay parameter in the transition function. Column (iii) of Table 4.2 reports the alternative estimate using $\pi_{t-1} - \pi^T$ as transition variable in both transition functions, an alternative to $\pi_{t+1} - \pi^T$ earlier. In this case, we estimate τ^L = -

0.739% and τ^U = 0.200% and find both of them to be significant at 1%. This confirms the reliability of our main estimate.

4.8 Conclusion

This chapter models the UK monetary policy for the post 1992 period accounting for open economy effects. There are two specific objectives of this chapter. First, we assessed whether or not monetary authorities consider a large negative and a large positive deviation of inflation from the target equally bad? And second, whether or not monetary policy responds to the open economic effects by responding to the foreign interest rates. And if yes, whether the degree of responsiveness affects by the inflation regime?

We estimate a foreign interest rate augmented Taylor rule using the three regime smooth transition autoregressive model and find a number of new findings for the UK monetary policy. First, we observe that monetary policy is forward looking and nonlinear; and policy response is asymmetric. Second, we find that monetary policy in UK has a deflationary bias because it does not respond to inflation when the expected inflation is below the lower band, respond mildly when it is within the bands and respond more rigorously when it exceeds the upper band. On the other hand, policy reaction to the output gap becomes more vigorous when economy is in the lower inflation regime compared to a sluggish respond when it is in the inner or upper regimes. Third, we find that policy always addresses to the effects of open economy by responding to the foreign interest rate irrespective to the inflation regime although the response is mild.

Chapter 5

The complex response of Monetary Policy[40]

5.1 Introduction

It is obvious that inflation is the central focus of monetary policy in UK as the Bank of England targets it explicitly. However, that does not imply that policy always only responds to inflation. Recent literature suggests that the UK policymakers respond to inflation together with asset prices and the output gap though the way that the policy responds to inflation may be different than the response to asset prices and the output gap (Clarida et al. 1998, Chadha et. al 2004, Bec et al. 2002, Martin and Milas, 2004).

[40] An earlier version of this chapter was presented in a staff seminar in Brunel University on March 8, 2006. I am grateful to participants for their helpful comments.

We attempted to address a part of this issue in the previous chapter and found that the UK monetary policy is nonlinear and policy only responds to asset prices together with inflation when expected inflation is far from the target[41]. This finding is vague and raises several questions. Does policy still respond to asset prices when asset price misalignment is small but inflation is far from the target? What is the policy response of the Bank of England when asset price misalignment is high but inflation is close to the target? Does the exchange rate adequately capture the open economy effect or does policy respond to the foreign interest rate as well as the exchange rate? The empirical literature, to our knowledge, is unclear on this point.

This chapter, therefore, aims to answer these questions systematically. In order to analyze these complex response of monetary policy, we begin by analyzing whether policymakers consider a separate asset price regime together with as inflation regime in the conduct of monetary policy, such that policy response on asset prices and inflation varies with large and small asset price misalignments and/or large and small deviations of inflation from the target. To do this, we employ multiple regime smooth transition autoregressive (MRSTAR) model (van Dijk and Franses, 1999). This model is flexible in nature and allows us to define multiple regimes using different types of asymmetries. In this chapter, we use two regimes for asset price misalignments and two regimes for inflation, making a total of four regimes, which we believe is sufficient to address the issues raised above.

[41] See chapter 3 and 4 for other findings.

The major contributions of this chapter are as follows. First, monetary policy in UK has regimes for both the exchange rate and inflation. We find that the Bank of England responds to inflation and exchange rate only when they are in their outer regimes. More precisely, the Bank responds to the exchange rate only if domestic currency undervaluation is more than 4.4% or overvaluation exceeds 5.1%. Similarly, policy only responds to inflation when expected inflation is less than 2% or greater than 2.75%.

Second, the policy response to exchange rate misalignment does not depend on the inflation regime but the response to inflation depends on the exchange rate regime. Third, policymakers only respond to output gap when they do not respond to asset prices and inflation, that is, when inflation and/or the exchange rate are in their inner regimes.

Fourth, exchange rate misalignment does not capture the full effect of the open economy as the Bank of England also responds to the foreign interest rate together with the REER misalignment. More specifically, we find that the behaviour of UK monetary policy is better described by a model which also includes the foreign interest rate. The response to the foreign interest rate, however, is not affected by the inflation and exchange rate regimes or by any other variables.

The plan of this chapter is as follows. Section 5.2 presents a brief literature review. Section 5.3 describes the methodology followed by the empirical estimates in section 5.4. Finally, section 5.5 concludes the chapter.

5.2. Multiple-regime STAR models in economics

5.2.1. Statistical model

5.2.1.1. Two regime model

MRSTAR model is a simple extension of the two regime smooth transition autoregressive (STAR) family models. We, therefore, begin with two regime models and then consider the multiple-regime case. As discussed in Luukkonen et al. (1988), Terasvirta and Anderson (1992), and Terasvirta (1994), the two regime STAR model can be written as:

$$y_t = \phi_1' x_t G(s_t;\gamma,\tau) + \phi_2' x_t (1 - G(s_t;\gamma,\tau)) + u_t \qquad u_t \sim iid(0,\sigma^2) \qquad (5.1)$$

where, $x_t = (1, \widetilde{x}_t')$, $\widetilde{x}_t = (y_{t-1}, \ldots, y_{t-p})'$, $\phi_i = (\phi_{i,0}, \phi_{i,1}, \ldots, \phi_{i,p})'$, and i=1,2; and $G(s_t;\gamma,\tau)$ is a continuous transition function bounded between zero and one.

Following Terasvirta and Anderson (1992) and Terasvirta(1994), we consider two alternative definitions of the transition function, $G(s_t;\gamma,\tau)$. First, the logistic function

$$G(s_t;\gamma,\tau) = 1-[1+e^{[-\gamma(s_{t-d}-\tau)/\sigma^2]}]^{-1}; \qquad \gamma>0 \tag{5.2}$$

and second, the exponential function

$$G(s_t;\gamma,\tau) = 1-e^{[-\gamma(s_{t-d}-\tau)^2/\sigma]}; \qquad \gamma>0 \tag{5.3}$$

In both equations, s_t is the transition variable with d as the delay parameter or the time horizon of the transition variable. The literature offers at least four different ways of defining s_t (van Dijk et al., 2002). It can be a lag dependent variable, an exogenous variable, a time trend or any functional form. γ is the slope variable which determines the smoothness of the change in the value of $G(s_t;\gamma,\tau)$ and thus the speed of transition from one regime to another; τ is the threshold between two regimes. σ is the standard deviation and σ^2 is the variance of s_{t-d}, which makes γ scale-free and yields easier interpretation (Granger and Terasvirta, 1993).

The logistic function (5.2) depicts a S-shape around τ. It monotonically increases along with s_{t-d} and yields an asymmetric adjustment toward equilibrium for both $s_{t-d}>\tau$ and $s_{t-d}<\tau$. In this case $G(s_t;\gamma,\tau)\to 0$ when $s_{t-d}\to -\infty$ and $G(s_t;\gamma,\tau)\to 1$ when $s_{t-d}\to +\infty$; thus $G(s_t;\gamma,\tau)$ is bounded between 0 and 1 where $G(s_t;\gamma,\tau)$=0.5

if $s_{t-d} = \tau$. In the extreme case, when $\gamma \to 0$, $G(s_t;\gamma,\tau)$ becomes a constant if $\gamma \to \infty$, there is a sharp transition at $s_{t-d} = \tau$ where $G(s_t;\gamma,\tau)$ jumps from 0 and 1 discontinuously. In the latter case, (5.1) becomes the threshold transition function along the line of Tong's (1983) TAR models.

The ESTAR function (5.3), on the other hand, takes a U-shape, which implies that there is a symmetric adjustment for both $s_{t-d} > \tau$ and $s_{t-d} < \tau$. A possible drawback of this equation is that the model becomes linear if either $\gamma \to 0$ or $\gamma \to \infty$. To avoid this drawback, Jansen and Terasvirta (1996) suggest alternative specification as:

$$G(s_t;\gamma,\tau) = 1 - [1 + e^{-\gamma(s_{t-d}-\tau^L)(s_{t-d}-\tau^U)/\sigma}]^{-1} \qquad (5.4)$$

Equation (5.4) is the quadratic logistic function, which provides the probability that $\tau^L \le s_{t-1} \le \tau^U$. This function has two important properties: (a) θ_{lt} becomes constant as $\gamma \to 0$ and (b) as $\gamma \to \infty$, $G(s_t;\gamma,\tau)=1$ if $\tau^L \le s_{t-1} \le \tau^U$ and $G(s_t;\gamma,\tau)=0$ if $s_{t-1} < \tau^L$ or $s_{t-1} > \tau^U$.

Eq. (5.1) combined with (5.2) yields the logistic smooth transition autoregressive (LSTAR) model while the combination of (5.1) accompanied by (5.4) defines quadratic logistic smooth transition autoregressive (QLSTAR) model. The selection procedure between LSTAR and QLSTAR is explained in the previous chapter. The structure of these models itself show that they describe distinct asymmetries. While the LSTAR model describes with signs asymmetries of the transition variable, the ESTAR or QLSTAR model describes size asymmetries.

5.2.1.2. Multiple regime models

The main limitation of two regime models is that they do not provide sign and size asymmetries together. Therefore, Eq (5.1) needs to be expanded to obtain a model that allows more than two distinct regimes. The number of regimes and type of asymmetries, however, depends on whether the economic modelling requires multiple regimes of the same transition variable or a combination of several transition variables.

For obtaining multiple regime STAR models using the same transition variable, the literature offers the following three regime STAR model (Madsen and Milas, 2005).

$$y_t = \phi_1' x_t G_1(s_t;\gamma,\tau) + \phi_2' x_t G_2(s_t;\gamma,\tau) + \phi_3' x_t (1 - G_1(s_t;\gamma,\tau) - G_2(s_t;\gamma,\tau)) + u_t \qquad (5.5)$$

The family of STAR models is flexible enough to provide asymmetries of more than one transition variable at a time. For instance, when obtaining a multiple-regime by the combination of two transition variables at a time, we get the following four-regime model (van Dijk and Franses, 1999).

$$y_t = [\phi_1' x_t G_1(s_{1t};\gamma_1,\tau_1) + \phi_2' x_t (1 - G_1(s_{1t};\gamma_1,\tau_1))] G_2(s_{2t};\gamma_2,\tau_2)$$
$$+ [\phi_3' x_t G_1(s_{1t};\gamma_1,\tau_1) + \phi_4' x_t (1 - G_1(s_{1t};\gamma_1,\tau_1))][1 - G_2(s_{2t};\gamma_2,\tau_2)] + u_t \qquad (5.6)$$

where $G_1(s_{1t};\gamma_1,\tau_1)$ provides two regime for s_{1t} and $G_2(s_{2t};\gamma_2,\tau_2)$ describes another two regime for s_{2t}.

There are four regimes in this model:

(a) $G_1(s_{1t};\gamma_1,\tau_1)\, G_2(s_{2t};\gamma_2,\tau_2)$ provides a probability that $s_{1t} \le \tau_1$ and $s_{2t} \le \tau_2$, which can be denoted as regime 1;

(b) $[1\text{-}G_1(s_{1t};\gamma_1,\tau_1)]\, G_2(s_{2t};\gamma_2,\tau_2)$ is the probability that $s_{1t} > \tau_1$ but $s_{2t} \le \tau_2$, is denoted by regime 2,

(c) $G_1(s_{1t};\gamma_1,\tau_1)[1\text{-}G_2(s_{2t};\gamma_2,\tau_2)]$ is another probability that $s_{1t} \le \tau_1$ but $s_{2t} > \tau_2$, say regime 3, and

(d) $[1\text{-}G_1(s_{1t};\gamma_1,\tau_1)][1\text{-}G_2(s_{2t};\gamma_2,\tau_2)]$ is the probability that $s_{1t} > \tau_1$ and $s_{2t} > \tau_2$. This can be denoted as regime 4.

5.2.2. The importance of STAR models

Although the STAR family model is a recently introduced econometric technique to analyze nonlinear and asymmetric behaviour of time series data, its use in economics and finance has increased significantly, for the following reasons. Firstly, economists are interested with the implication of a positive/negative and/or large/small deviations of many macroeconomic and financial variables. The STAR family model allows us to model these asymmetries. Secondly, this family models estimate the threshold parameter(s) endogenously which may be very useful for the economic analysis (see next section). Thirdly, it provides a smooth transition between two extreme regimes, compared to an abrupt jump in threshold or TAR models (Tong, 1983).

This model, however, should be used cautiously for the following reasons. First, it is very hard to estimate the slope parameter(s) precisely as it requires a large sample size. It is well known in the literature that the small sample bias is more acute in nonlinear models than the linear one (van Dijk et al. 2003). Second, this family model considers only stationary variable(s). So, the choice of this model may be inappropriate if variables contain unit roots.

Third, if the slope of transition function tends to infinity the transition between two regimes takes rather abrupt and the model translates to TAR or it makes almost no difference with Markov-switching model. In this case, the transition between regimes becomes abrupt rather than a smooth transition. Finally, as discussed earlier, a small sample may produce a bias result while testing linearity or nesting transition functions.

5.2.3 The use of multiple regime STAR models in economics

One of the areas in economics that provides ample evidence of nonlinearity is the business cycle. Although economic theories identify at least four different stages in a cycle, empirical works were confined only to two regimes tills early 1990s due to unavailability of a suitable model. A large number of empirical works, therefore, used linear regression models, two regime Markov switching models, and threshold autoregressive models to analyze the business cycle (see Hamilton, 1989 and Tiao and Tsay, 1994 and references there in). Against this tradition, Bodlin (1996) uses a three regime Markov switching model and Tiao and Tsay (1994) use a four regime SETAR model to analyze the US business cycle.

Granger and Terasvirta (1993), Terasvirta (1994) and van Dijk and Franses (1999) introduce multiple regime nonlinear models. Van Dijk and Franses (1999) analyze the US business cycle over 1947Q1-1995Q2 using a four regime smooth transition autoregressive model. They use two LSTAR functions, one for GNP growth and another for "depth of recession", to obtain four regimes.

Using a four regime STAR model, Dufrenot et al. (2003) analyze the role of the US monetary policy in business cycle for the period of 1975Q1 to 1998Q4. They define two regimes for the output gap and two regimes for the term structure of interest rate and find that the impact of monetary policy on business cycle is asymmetric.

Bec et al. (2004) use a three regime STAR model using ESTAR and SETAR functions to analyze the dynamic behavior of the real exchange rate. They find that the real exchange rate is nonlinear mean reverting due to the transaction costs.

Madsen and Milas (2005) employ a three regime STAR model to analyze the price-dividend relationship in UK and USA for the period of 1871 to 2002. Using a cointegrating vector as the transition variable they find that the high inflation and deflation regimes matter in the convergence process.

Arghyrou et al. (2005) use a three regime STAR model to analyze the dynamic behavior of inflation in UK for the period of 1965 to 2001. They find that the persistence of inflation is nonlinear, as inflation adjusts rapidly when prices are further from the steady state and when prices are above the steady state. For this reason, they argue that monetary policy that considers a uniform price adjustment would be unreliable.

Regarding the research on monetary policy, a number of recent theoretical and empirical studies suggest that the policy is nonlinear. Most empirical works, however, are based on two-regime models (Schaling, 1999; Dolado, Maria-Dolores and Naveria, 2004, Martin and Milas, 2004). Kesriyeli et al. (2004) is the only paper, to our knowledge, that uses the multiple-regime STAR model to analyze monetary policy reaction functions for UK, USA and Germany. They define two regimes for time trend and two regimes for the interest rate, making a total of four regimes. They find that monetary policy is nonlinear and the four-regime STAR model provides a better fit of the reaction function over the linear model for these three countries.

5.3 Methodology

5.3.1 Linear monetary policy reaction function

The previous chapter clearly showed that the asset price augmented Taylor rule outperforms the simple Taylor rule. This conclusion is consistent with other empirical analysis (Chadha et al., 2004, Adam et al. 2005 and Clarida et al. 1998 and references therein). We therefore do not repeat the same experiment in this chapter but start with an asset price augmented Taylor rule as the basic linear model. The typical monetary policy reaction function we consider takes a form:

$$i_t^* = \bar{i} + \rho_{if} E_{t-1} i_{t+n}^f + \rho_\pi E_{t-1}(\pi_{t+n} - \pi^T) + \rho_y E_{t-1}(y_{t+n} - y_{t+n}^P) + \rho_e E_{t-1}(e_{t+n} - e_t^E) + u_t \tag{5.7}$$

where ρ_{if}, ρ_π, ρ_y and ρ_e are parameters to be estimated and are expected to be positive.

Equation (5.7) states that the desired nominal interest rate (i_t^*) depends on the equilibrium nominal interest rate ($\bar{i}$), the foreign interest rate (i_{t+n}^f) expected for t+n, expected rate of inflation (π_{t+n}) relative to the inflation target (π^T), the actual output (y_{t+n}) relative to the potential output (y_{t+n}^P) expected for time t+n, and deviation of the real exchange rate (e_{t+n}) from the equilibrium (e_t^E) expected for t+n where e_{t+n} is defined as the real price of domestic currency in terms of foreign currencies. Finally, E_{t-1} is the expectation formed for t+n based on the lag information and $u_t \sim iid(0,\sigma^2)$.

As in Clarida et al. (1998) and Woodford (2003), we define the observed nominal interest rate as the weighted average of the lagged interest rate and the desired rate:

$$i_t = \rho_i i_{t-1} + (1-\rho_i)i_t^*; \qquad 0 < \rho_i < 1 \qquad (5.8)$$

Combining (5.7) and (5.8), we obtain

$$i_t = \rho_i i_{t-1} + (1-\rho_i)\{\bar{i} + \rho_{if} E_{t-1} i_{t+n}^f + \rho_\pi E_{t-1}(\pi_{t+n} - \pi^T) + \rho_y E_{t-1}(y_{t+n} - y_{t+n}^P) + \rho_e E_{t-1}(e_{t+n} - e_t^E)\} + e_t$$

Re-arranging the terms yields,

$$i_t = i^* + \rho_i i_{t-1} + (1-\rho_i)\{\rho_{if} E_{t-1} i_{t+n}^f + \rho_\pi E_{t-1}(\pi_{t+n} - \pi^T)$$

$$+\rho_y E_{t-1}(y_{t+n} - y^P_{t+n}) + \rho_e E_{t-1}(e_{t+n} - e^E_t)\} + e_t \qquad (5.9)$$

where, $i^* = (1-\rho_t)\bar{i}$ and e_t is the combined error generated from (5.7) and (5.8).

Equation (5.9) is the linear model to be estimated. It combines the effect of REER and the foreign interest rate in the Taylor rule.

5.3.2 Multiple regimes monetary policy reaction function

Having defined a baseline linear reaction function, we now proceed to introduce a multiple regime nonlinear reaction function to asses the complex response of monetary policy. Since our sample size is relatively small as we model UK monetary policy for the inflation targeting period, we follow the following selective strategies in nonlinear modelling.

First, as the UK is a relatively open and liberal economy, we assume that the Bank of England responds to the foreign interest rate all the time to minimize foreign adverse effects in the economy. For this reason, we formulate a nonlinear model where the foreign interest rate is assumed to be regime free[42]. Other variables such as deviations of inflation from the target, the output gap and the REER gap are made regime dependent on the assumptions that central bank's policies may vary for large and

[42] This assumption is based on the findings of chapter 4.

small deviations of these variables from their targets or equilibrium levels. This assumption is made based on the preliminary analysis of our data.

Second, although statistical theory provides a rigorous method of selecting an appropriate transition function (mainly between LSTAR and QLSTAR), we select the quadratic logistic function without using statistical criteria for three reasons. First, our sample size is relatively small. Second, monetary theory prefer QLSTAR function over LSTAR as policymakers keep more concerned with size asymmetries than sign (see Martin and Milas, 2004 for the discussion of this point). Third, our conclusion in the previous chapters shows that QLSTAR model outperforms the LSTAR model.

Third, we use $\pi_{t+n} - \pi^T$ and $e_{t+n} - e_t^E$ as transition variables, which provides two (inner and outer) regimes for inflation and two (inner and outer) regime for the exchange rate, making a total of 4 regimes[43].

After considering these assumptions, we now formulate the following four regime monetary policy reaction function which combines the inflation and the exchange rate regime together (van Dijk and Franses, 1999).

[43] We are also interested to have regimes for the output gap but is computationally unfeasible for a sample size we have.

$$i_t = \bar{i} + \rho i_{t-1} + (1-\rho)[\rho^f i_t^f + M_{1t}\theta_{1t}\theta_{2t} + M_{2t}(1-\theta_{1t})\theta_{2t}$$

$$+ M_{3t}\theta_{1t}(1-\theta_{2t}) + M_{4t}(1-\theta_{1t})(1-\theta_{2t})] + \varepsilon_t \qquad (5.10)$$

Where,

$$\theta_{1t} = \Pr\{\phi^L \leq (e_{t+p} - e_{t+p}^E) \leq \phi^U\}$$

$$= 1 - [1 + \exp\{-\gamma_1 (e_{t+p} - e_{t+p}^E - \phi^L)(e_{t+p} - e_{t+p}^E - \phi^U) / \sigma^2_{(e_{t+p} - e_{t+p}^E)}\}]^{-1} \qquad (5.11)$$

$$\theta_{2t} = \Pr\{\tau^L \leq (\pi_{t+q} - \pi^T) \leq \tau^U\}$$

$$= 1 - [1 + \exp\{-\gamma_2 (\pi_{t+q} - \pi^T - \tau^L)(\pi_{t+q} - \pi^T - \tau^U) / \sigma^2_{(\pi_{t+q} - \pi^T)}\}]^{-1} \qquad (5.12)$$

$$M_{1t} = k_{11} E_{t-1}(\pi_{t+n} - \pi^T) + k_{12} E_{t-1}(y_{t+n} - y_{t+n}^P) + k_{13} E_{t-1}(e_{t+n} - e_{t+n}^E) \qquad (5.13)$$

$$M_{2t} = k_{21} E_{t-1}(\pi_{t+n} - \pi^T) + k_{22} E_{t-1}(y_{t+n} - y_{t+n}^P) + k_{23} E_{t-1}(e_{t+n} - e_{t+n}^E) \qquad (5.14)$$

$$M_{3t} = k_{31} E_{t-1}(\pi_{t+n} - \pi^T) + k_{32} E_{t-1}(y_{t+n} - y_{t+n}^P) + k_{33} E_{t-1}(e_{t+n} - e_{t+n}^E) \qquad (5.15)$$

$$M_{4t} = k_{41} E_{t-1}(\pi_{t+n} - \pi^T) + k_{42} E_{t-1}(y_{t+n} - y_{t+n}^P) + k_{43} E_{t-1}(e_{t+n} - e_t^E) \qquad (5.16)$$

and, $\varepsilon_t \sim iid(0, \sigma^2)$

Eq (5.10) states that the observed nominal interest rate (i_t) depends on the equilibrium nominal interest rate ($\bar{i}$), the lag dependent variable (i_{t-1}), the foreign interest rate (i_{t+n}^f) and four augmented linear Taylor rules (M_{it}, for i=1 to 4). There are two transition functions (θ_{1t} and θ_{2t}) in this model which determine the four regimes.

As shown in Eq (5.11), the first transition function, θ_{1t} gives the probability that the REER is close to equilibrium or lies between the lower threshold (ϕ^L) and the upper threshold (ϕ^U). Therefore, (1-θ_{1t}) is the probability that the REER is far from the equilibrium level, i.e $(e_{t+p} - e^E_{t+p}) < \phi^L$ or $(e_{t+p} - e^E_{t+p}) > \phi^U$. In other words, it is the probability that REER misalignment is large.

Likewise, the second transition function, θ_{2t}, is the probability that deviations of inflation from the target ($\pi_{t+q} - \pi^T$) lie between the lower threshold (τ^L) and the upper threshold (τ^U). This implies that (1-θ_{2t}) is the probability that either $(\pi_{t+q} - \pi^T) < \tau^L$ or $(\pi_{t+q} - \pi^T) > \tau^U$ holds.

Notice that $\gamma_1 > 0$ and $\gamma_2 > 0$ are slope parameters which are made dimension-free by dividing them by the variance of $(e_{t+p} - e^E_{t+p})$, that is $\sigma^2_{(e_{t+p}-e^E_{t+p})}$ and by the variance of ($\pi_{t+q} - \pi^T$), that is $\sigma^2_{(\pi_{t+q}-\pi^T)}$, respectively. The subscripts p and q are the time horizon of the transition variables. The properties of these functions are discussed in section 5.2.1.

Eq. 5.10 simplifies to the linear augmented Taylor rule in Eq (5.9) if

$$H_0 : k_{1i} = k_{2i} = k_{3i} = k_{4i} \qquad \text{for i=1 to 3} \tag{5.17}$$

Alternatively, if $\gamma_1 = \gamma_2 = 0$, Eq. (5.10) also collapses to the linear model in Eq. (5.9). Further, if one of the slope parameters (γ_1 or γ_2) is zero, the four regime STAR model translates to the two regime quadratic logistic model. In this case Eq. (5.10) will be able to describe the size asymmetry of only one transition variable at a time.

5.3.2.1. Interpretation of the model

The main attraction of Eq (5.10) has two folds – the estimate of thresholds (ϕ^L, ϕ^U, τ^L and τ^U) and the estimate of augmented Taylor rules (M_{it}, for i=1 to 4). Notice that the thresholds are endogenously determined and they can be interpreted as the "policy alter lines". This is because the central banks' response to the exchange rate and inflation varies between the inner and outer regimes. For instance, policymakers consider that the exchange rate misalignment is high if it is less than ϕ^L or greater than ϕ^U. Similarly policymakers think that inflation is far from the target if it is less than τ^L or greater than τ^U.

Taylor rules, M_{1t} to M_{4t}, describe policy responsiveness in each regime. The behavior of policymaker in regime 1 is described by M_{1t}. This is the regime where exchange rate misalignment is small and inflation is close to the target, i.e $\phi^L \le (e_{t+p} - e_{t+p}^E) \le \phi^U$ and $\tau^L \le (\pi_{t+q} - \pi^T) \le \tau^U$.

The behavior of policymaker in regime 2 is given by M_{2t} where the exchange rate misalignment is large but inflation is close to the target, that is $(e_{t+p} - e_{t+p}^E) < \phi^L$ or $(e_{t+p} - e_{t+p}^E) > \phi^U$ and $\tau^L \le (\pi_{t+q} - \pi^T) \le \tau^U$.

In regime 3, REER misalignment is low but inflation is not close to the target [$\phi^L \le (e_{t+p} - e_{t+p}^E) \le \phi^U$ and $(\pi_{t+q} - \pi^T) < \tau^L$ or $(\pi_{t+q} - \pi^T) > \tau^U$].

Finally, in regime 4, REER misalignment is large and inflation is also not close to the target, that is, [$(e_{t+p} - e_{t+p}^E) < \phi^L$ or $(e_{t+p} - e_{t+p}^E) > \phi^U$ and $(\pi_{t+q} - \pi^T) < \tau^L$ or $(\pi_{t+q} - \pi^T) > \tau^U$]. The behaviour of policymaker in this regime is given by M_{4t}.

5.3.2.2. Features of nonlinear policy rules

Table 5.1 summaries the analytical framework of our nonlinear model. We assume that the regime 1 as the "normal" period where asset prices and inflation both remains in their inner regimes. In this situation, it is rational to expect that policymakers respond to the output gap because they may not respond to asset prices and inflation. Therefore, we expect at least $k_{12} \neq 0$ in M_{1t}.

In regime 2, exchange rate misalignment is large but the inflation remains close to the target. As a result, monetary policy responds to the asset price misalignment. Therefore, we expect $k_{23} \neq 0$ in M_{2t}. Regime 3 is just the reverse of regime 2 where exchange rate misalignment is small but inflation is far from the target. In this situation, it is rational to expect that policy response to inflation is vigorous. We expect $k_{31} \neq 0$ in M_{3t}. This implies that monetary policy is influenced by asset prices in regime 2 and by inflation in regime 3.

Table 5.1: Synthesis of nonlinear monetary policy#

Regime	Reaction function	Asset price regime	Inflation regime	Effects on monetary policy
I	M_{1t}	$\phi^L \leq (e_{t+p} - e^E_{t+p}) \leq \phi^U$	$\tau^L \leq (\pi_{t+q} - \pi^T) \leq \tau^U$	Normal period
II	M_{2t}	$(e_{t+p} - e^E_{t+p}) < \phi^L$ or $(e_{t+p} - e^E_{t+p}) > \phi^U$	$\tau^L \leq (\pi_{t+q} - \pi^T) \leq \tau^U$	Asset price effect
III	M_{3t}	$\phi^L \leq (e_{t+p} - e^E_{t+p}) \leq \phi^U$	$(\pi_{t+q} - \pi^T) < \tau^L$ or $(\pi_{t+q} - \pi^T) > \tau^U$	Inflation effect
IV	M_{4t}	$(e_{t+p} - e^E_{t+p}) < \phi^L$ or $(e_{t+p} - e^E_{t+p}) > \phi^U$	$(\pi_{t+q} - \pi^T) < \tau^L$ or $(\pi_{t+q} - \pi^T) > \tau^U$	Both effects

abstracted from Equation 5.10

In regime 4, actual inflation is far from the target and the exchange rate misalignment is also large. We might expect $k_{41} \neq 0$ and $k_{43} \neq 0$ in M_{4t}, implies both (asset price and inflation) effect in monetary policy.

It is important to consider a standard macroeconomic principle in this context. Theory provides ample evidences that the exchange rate over valuation creates a downward pressure on inflation. On the contrary, if there is a large undervaluation then it creates additional upward pressure on inflation. In this context, we expect $k_{31} < k_{41}$ if policymakers target inflation explicitly.

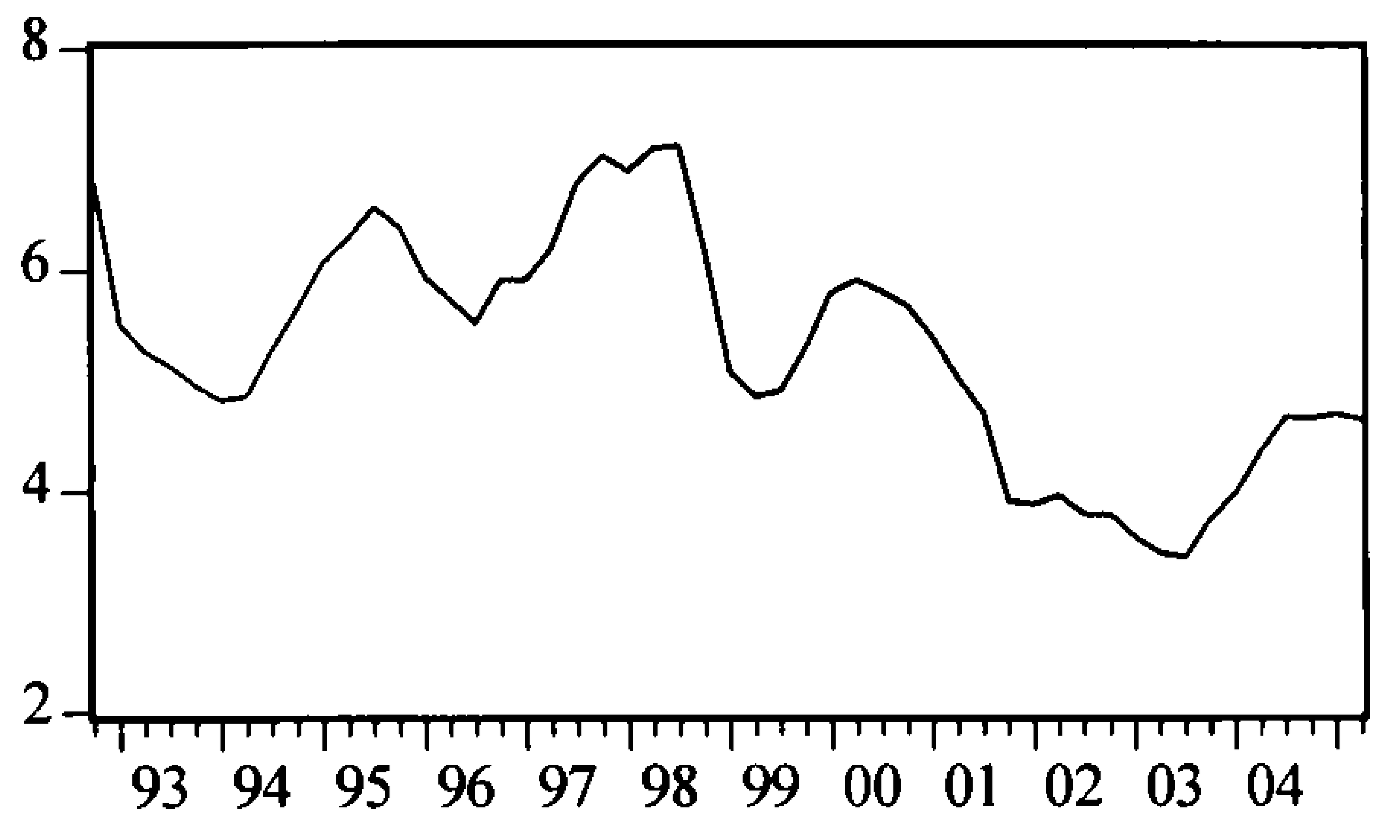
5.4 Empirical estimates

5.4.1 The data

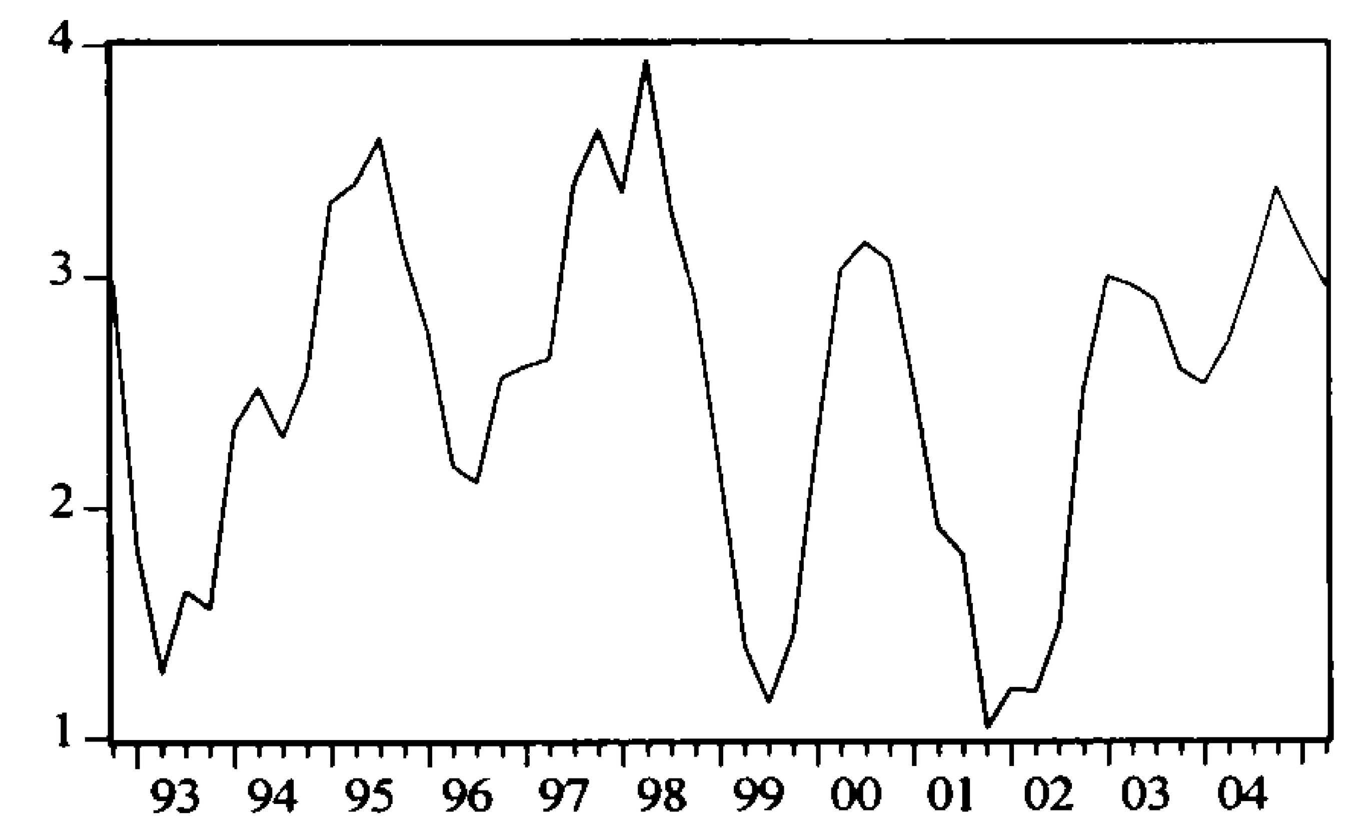
We employ UK quarterly data for the period of 1992Q4 to 2005Q2. Following usual practice, the three month Treasury Bill rate is used as a measure of the short term interest rate, i_t. The US Federal fund rate is employed as the foreign nominal interest rate, i_t^f. The four-quarter change in the retail price index (RPI) is used as a measure of inflation, π_t. Likewise, real GDP is used to measure output, y_t, and the trade weighted real effective exchange rate index (REER) is used to measure the real exchange rate, e_t, where an increase indicates a real depreciation of sterling against foreign currencies. All data, except for REER, are obtained from the IFS and REER from the OECD-Historical statistics, both collected by DataStream.

Figure 5.1: Plots of variables (Sample period: 1992Q4 – 2005Q2)

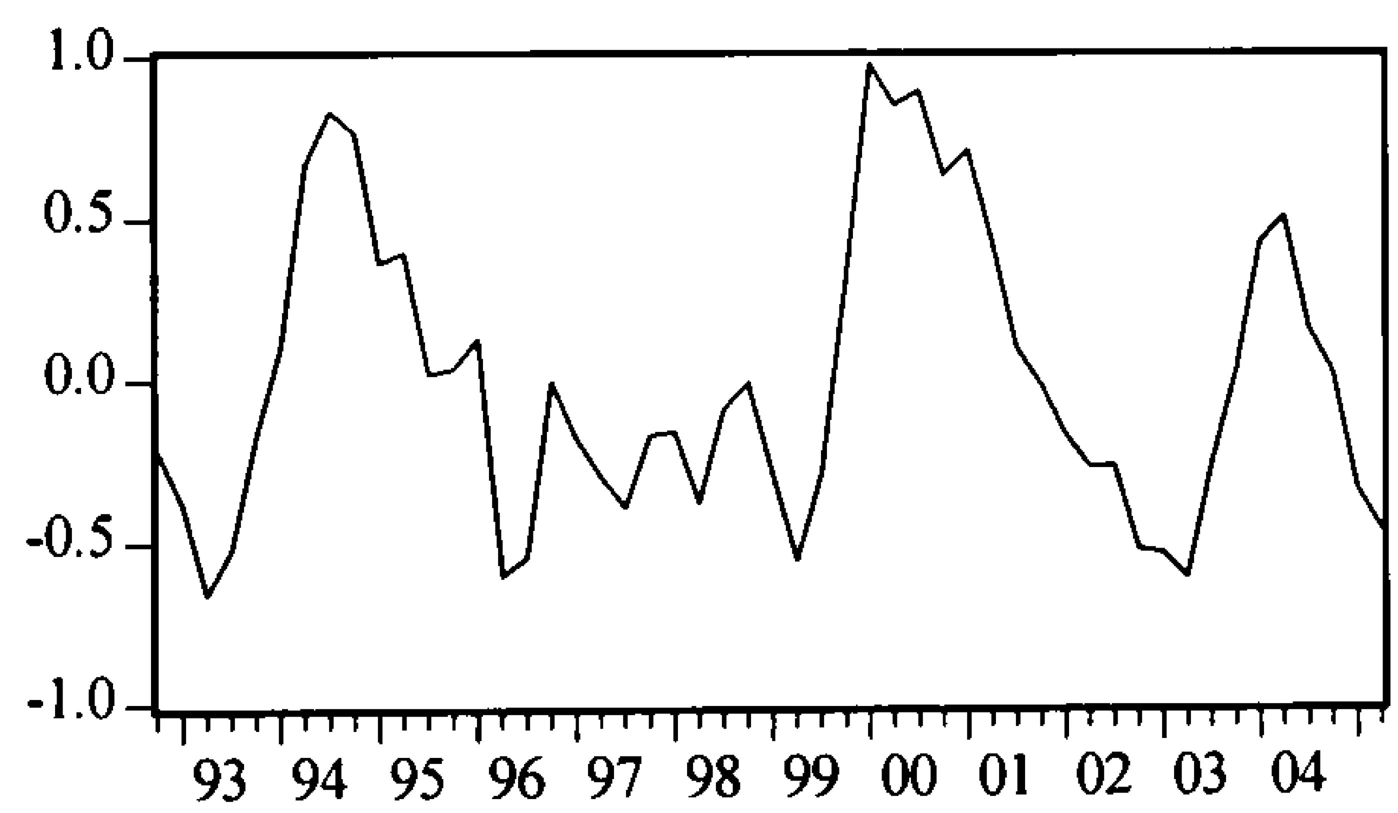
A. Interest rate, i_t



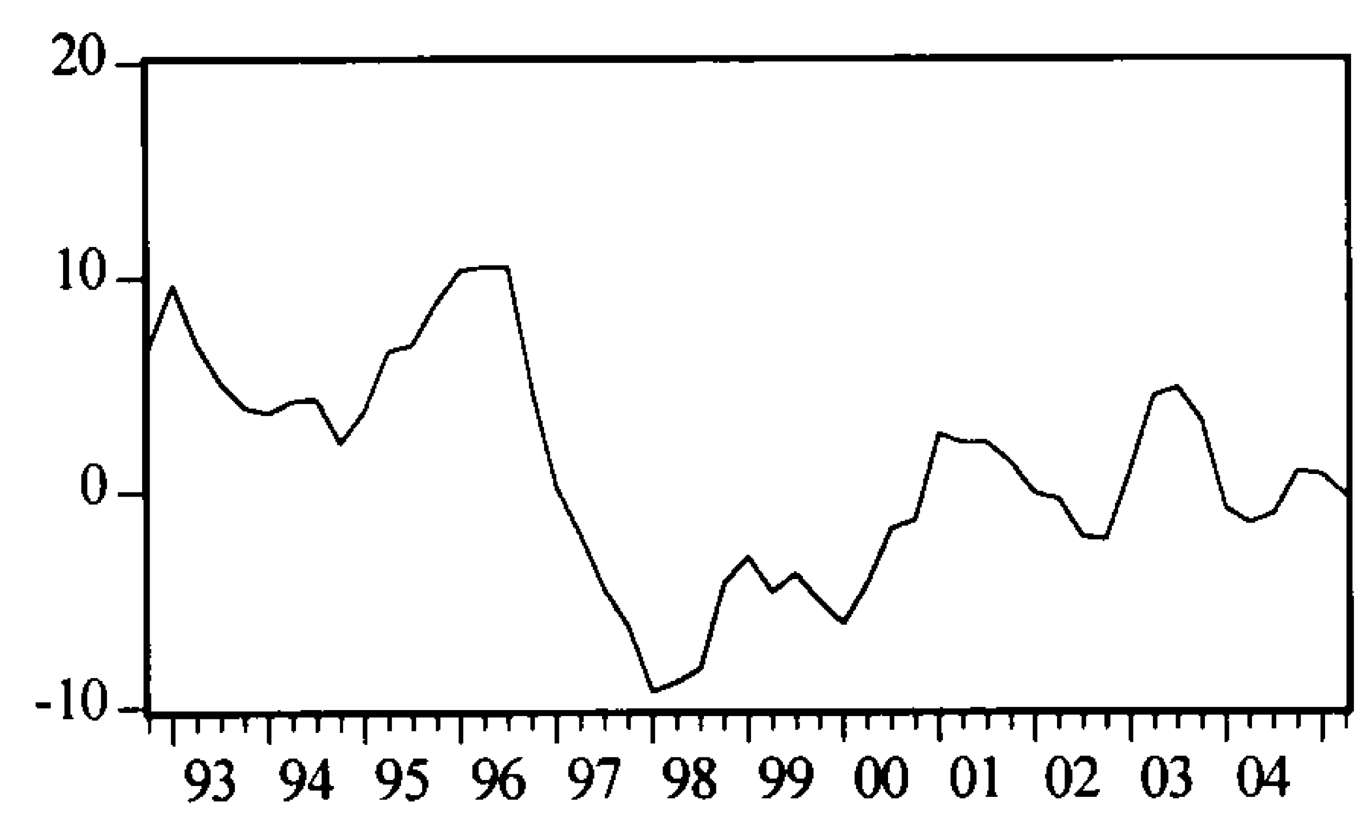
B. Inflation, π_t



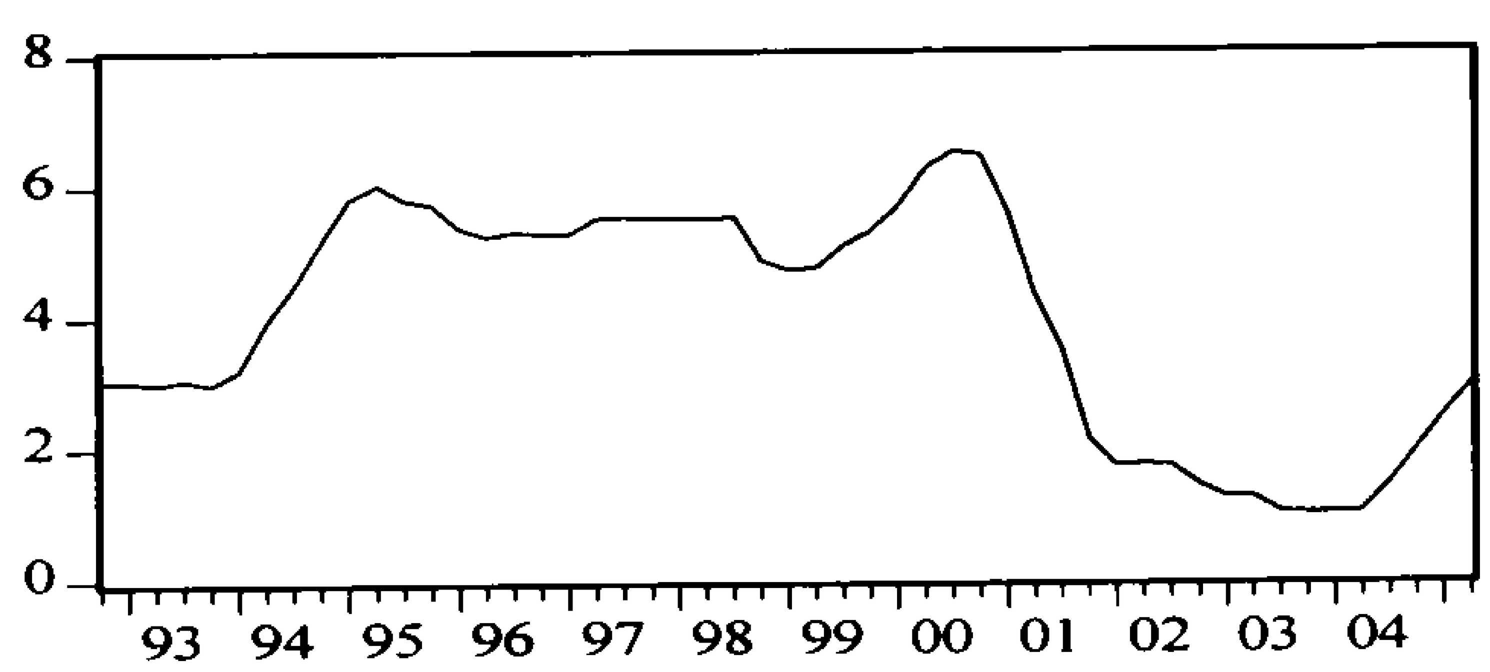
C. Output gap, $y_t - y_t^*$



D. REER gap, $e_t - e_t^*$



E. Foreign interest rate, i_t^f



Following the Bank of England's decade-long practice, we set π^T=2.5% which gives $\pi_t - \pi^T$ as deviations of inflation from the target. On the other hand, the potential output and the equilibrium REER are not readily available. The literature offers a variety of de-trending techniques to obtain these variables from the actual series. Following a popular choice, we use the Hordirc-Prescott de-trending method to obtain potential output (y_t^P) and the equilibrium REER (e_t^E). The output gap is then obtained as y_t-y_t^P and the REER misalignment as e_t-e_t^E. Figure 5.1 shows the plots of variables.

As in the previous chapter, we employ augmented Dickey-Fuller (1979) and Phillips-Perron (1988) tests to test the stationary properties of the variables[44]. Table 5.2 shows the test results. We find that the order of integration of i_t and i_t^f is ambiguous but following Clarida et al. (1998) and Martin and Milas (2004), among others, we treat them as I(0). Other variables (π_t, y_t-y_t^P and e_t-e_t^E) are found to be I(0) at 5%.

[44] See chapter 3 for the nonlinear unit root tests for deviations of inflation from the target and the real exchange rate gap.

Table 5.2: Unit root tests (Sample period: 1992Q4 – 2005Q2)

Variable Name	Description	ADF Test	PP Test
i_t	3-months Treasury Bill Rate	-3.15	-3.82
π_t	$(\log RPIX_t - \log RPIX_{t-4}) * 100$	-3.42	-3.45
$y_t - y_t^P$	Output gap	-3.88	-3.07
$e_t - e_t^E$	Real Effective Exchange Rate Index gap [an increase indicates a real depreciation of sterling against foreign currencies)	-2.83	-2.91
i_t^f	US 3-months Federal Fund Rate	-2.39	-2.42

Note: (a) ADF and PP tests include constant and time trend for i_t and only constant to other four variables.

(b) Critical values (excluding trend in the test) for the ADF and PP tests are -3.56, -2.91 and -2.59 at at 1%, 5% and 10% respectively. Critical values which consider the time trend and constant term in the tests are -4.15, -3.50 and -3.18 at 1%, 5% and 10% respectively.

Data sources: OECD Historical series and IFS, both collected by Datastream

5.4.2 Linear estimates

We employ the generalized method of moments (GMM) to estimate all linear and nonlinear reaction functions in this chapter. We use a constant and up to five lags of all variables as instrument set (Clarida et al., 1998 and Martin and Milas, 2004). As the number of instruments is greater than the number of parameters to be estimated, we test the over identifying restrictions to make sure that instruments are orthogonal to the error term[45].

We experiment various combination of lead/lag relationships ranging from the 4th lag to 4th period ahead in Eq.(5.9) but find a best results when using n=1 for output and inflation and n=0 for the foreign interest rate and the exchange rate. Column 1 of Table 5.3 presents estimates of this model.

As in the previous chapters and other empirical literature (for instance Kharel et al. 2006, Martin and Milas, 2004, Clarida et. al., 1998 and Nelson, 2000), our linear model satisfies the dynamic stability criterion, as we find $\rho_{\pi}>1$. We also find that policymakers attach more weights to inflation followed by the output gap. The coefficients of exchange rate misalignment and the foreign interest rates are also significant at 1%. This implies that the Bank of England responds to the foreign interest rates and the exchange rate misalignment together with inflation and output.

There is no sign of misspecification in the estimate. The null of normality is not rejected. Also, the estimate does not reject the null hypothesis that the overidentifying restrictions are satisfied, which implies that the instruments are orthogonal to the error term.

[45] See Chadha et al. (2004) and also chapter 3 and 4 for more discussion of orthogonal conditions.

Table 5.3: Linear reaction functions: GMM estimates (1992Q4-2005Q2)

Parameters	(i)	(ii)	(iii)
i^*	0.444 (0.141)*	0.554 (0.247)*	0.698 (0.072)*
ρ	0.815 (0.047)*	0.825 (0.014)*	0.826 (0.023)*
ρ^f	0.447 (0.062)*	0.529 (0.036)*	0.265 (0.061)*
ρ_π	1.272 (0.317)*	1.837 (0.166)*	1.568 (0.214)*
ρ_y	0.925 (0.500)**	1.508(0.304)*	0.495 (0.220)**
ρ_e	0.084(0.037)*	0.160 (0.310)	0.048 (0.021)**
$\overline{R}^2$	0.922	0.920	0.913
Standard error	0.295	0.305	0.335
Normality	1.257 [0.533]	2.523 [0.128]	1.011 [0.592]
J-statistics	0.204	0.239	0.212
p-value	0.757	0.893	0.835

*Note: Numbers in (.) and [.] are standard errors and the probability values of the test statistics respectively. P-value is the probability value of the test that the over identified restriction is satisfied under null. A constant and up to five lags of all variables are used as instruments. * and ** indicate significant at 1% and 5% respectively. The interest rate, deviations of inflation from the target and the output gap are considered to be endogenous variables.*

To check robustness, we estimate Eq. (5.9) using two alternative specifications. First, we use the REER itself as an alternative to the REER misalignment. As shown in column (ii) of Table 5.2, ρ_e is found to be insignificant in this case. This implies that the authorities respond to the REER misalignment rather than REER index. Secondly, we use the EU money market rate as an alternative to the US Federal fund rate. The estimate, column (iii) of Table 5.1, does not alter our main findings.

5.4.3. Nonlinear estimates

5.4.3.1 General strategy

Considering our sample size, we adopt the following strategies for nonlinear estimates. First, the specification of Taylor rules in nonlinear estimate is made consistent to the linear Taylor rule. This implies that we set n=1 for the inflation and output and n=0 for the REER and the foreign interest rate for all regimes.

Second, as discussed in the literature review section earlier, finding an appropriate delay parameter is vital in the STAR model. Following the standard practice (Martin and Milas 2004 and Madsen and Milas 2005), we conduct a grid-search of different combination of p and q ranging from –4 to 4 in Eq 5.10 and choose the one which provides the best estimate.

Notice that there is a further grid-search of slope and thresholds for each combination of p and q. After a numerous experiments, we confirm that the combination of p=0 and q=1 provides the best results, with the lowest standard error and significant thresholds. Therefore, we use $e_t - e_t^E$ and $\pi_{t+1} - \pi^T$ as transition variables.

Third, estimating a full phased STAR model by GMM is almost impossible in a small size we have. Considering this constraint, we first estimate Eq. (5.10) by OLS and then again re-estimate the same model by GMM imposing nuisance (slope and threshold) parameters that were obtained from the OLS estimate. Therefore, the estimates of the nuisance parameters and their standard errors reported in Table 5.4 are estimated by the OLS and other parameters and tests are obtained by the GMM.

Fourth, we do not use any statistical criterion to select the number of regimes and the transition variable in our nonlinear reaction functions due to the fact of small sample size. Rather we estimate all possible nonlinear models and report the best result in Table 5.4.

Firth, we follow a general to specific approach while estimating the nonlinear model. In the process, we exclude insignificant parameters and allow some parameter restrictions in the final estimate reported in Table 5.4.

5.4.3.2 The estimates and discussion

Column 1 of Table 5.4 presents the GMM estimate of our nonlinear model, Eq. (5.10). The estimate is free from any misspecification as overidentifying restriction is satisfied and there is no sign of non-normality. Further, we find a lower standard error in this estimate than any other linear and nonlinear models reported in this chapter. The issue of linearity tests, that is Eq. (5.17), does not arise in this estimate as the structure of the Taylor rule in each regime is completely different. Therefore, the nonlinear estimate can not be collapsed to the linear model in Eq. 5.9. This implies that the four-regime reaction function better describes the UK monetary policy than the linear one.

As discussed earlier, there are two key estimates in this model – the thresholds and four augmented Taylor rules. Regarding thresholds, we estimate ϕ^L = -5.11% and ϕ^U = 4.37% using $e_t - e_t^E$ as a transition variable and reject the null that $\phi^L = \phi^U$. This implies that the economy is in the inner exchange rate regime when $-5.11 \leq (e_t - e_t^E) \leq 4.37$. Consequently, the economy is in the outer exchange rate regime when $(e_t - e_t^E) < -5.11$ or $(e_t - e_t^E) > 4.37$. Similarly, we estimate τ^L = -0.52% and τ^U = 0.260% for the second transition variable, $\pi_{t+1} - \pi^T$, which implies that the lower inflation boundary $(\pi^T - \tau^L)$ and the upper inflation boundary $(\pi^T + \tau^U)$ to be 1.98% and 2.76% respectively. Therefore, the economy remains in the inner inflation regime when $1.98 \leq \pi_{t+1} \leq 2.76$ and in the outer inflation regime when $\pi_{t+1} < 1.98$ or $\pi_{t+1} > 2.76$. Further, we reject the probability that $\tau^L = \tau^U$ and $(\pi^T - \tau^L + \pi^T + \tau^U)/2 = 2.5\%$ under the null hypothesis, which supports the finding of previous chapters that the BoE keep inflation within a range rather than pursuing a point target of 2.5% (see also Martin and Milas, 2004).

Table 5.4: Nonlinear reaction functions: GMM estimates (1992Q4-2005Q2)

Parameters	Main estimate (i)	Alternative estimates (ii)	(iii)	(iv)
i^*	0.511 (0.013)*	0.801 (0.038)*	0.551 (0.034)*	0.546 (0.023)*
ρ	0.854 (0.004)*	0.750 (0.010)*	0.811 (0.007)*	0.815 (0.006)*
ρ^f	0.361 (0.009)*	0.436 (0.010)*	0.528 (0.025)*	0.514 (0.011)*
k_{12}	2.829 (0.204)*	1.073 (0.114)*	1.281 (0.230)*	3.273 (0.114)*
k_{23}	0.062 (0.01)*	0.037 (0.007)*	0.041 (0.008)*	0.044 (0.005)*
k_{31}	2.611 (0.100)*	1.501 (0.056)*	1.655 (0.006)*	1.824 (0.061)*
k_{41}	2.845 (0.080)*	2.022 (0.119)*	1.709 (0.087)*	1.500 (0.068)*
k_{43}	0.062 (0.001)*	0.037 (0.007)*	0.041 (0.008)*	0.044 (0.005)*
1st TV	$e_t - e_t^*$	$e_t - e_t^*$	$e_t - e_t^*$	$e_t - e_t^*$
γ_2	1.78	1.78	1.78	1.78
ϕ^L	-5.112 (0.107)*	-5.112 (0.107)*	-5.112 (0.107)*	-5.112 (0.107)*
ϕ^U	4.368 (0.248)*	4.368 (0.248)*	4.368 (0.248)*	4.368 (0.248)*
2nd TV	$\pi_{t+2} - \pi^*$	$\pi_{t+1} - \pi^*$	$\pi_{t+1} - \pi^*$	$\pi_{t+1} - \pi^*$
γ_1	358	4.95	4.95	4.95
τ^L	-0.522 (0.038)*	-0.522 (0.038)*	-0.522 (0.038)*	-0.522 (0.038)*
τ^U	0.268 (0.071)*	0.268 (0.071)*	0.268 (0.071)*	0.268 (0.071)*
$\bar{R}^2$	0.954	0.953	0.936	0.952
s.e	0.233	0.237	0.277	0.241
Norm.	1.189 [0.515]	0.957 [0.619]	1.257 [0.533]	0.837
J-stat	0.258	0.261	0.274	0.657
p-value	0.997	0.997	0.988	0.994
$H_0: k_{31}=k_{41}$	17.758 [0.001]	17.83 [0.000]	2.508 [0.081]	17.017 [0.00]

Note:

(a) Column (i) is the estimate of Eq (5.10). Column (ii) use three year moving average to proxy the equilibrium level of REER as an alternative to the HP filter trend. Column (iii) use the EU money market rate as an alternative to the US rate. Column (iv) uses RPI instead of RPIX as a measure of inflation.

(b) The interest rate, deviations of inflation from the target and the output gap are considered to be endogenous variables.

(c) (.) is the standard error and [.] is the probability value of the test statistics. TV is the transition variable. s.e. is the standard error. Norm is the F-test for normality. J-stat is the value of the GMM objective function. P-value is the probability value of the test that the over identified restriction is satisfied under null.

(d) A constant and up to 4^{th} lags of all variables are used as instruments for the estimates.

*(e) * and ** indicate significant at 1% and 5% respectively.*

The behaviour of policymakers in each regime can be described as follows: First, policymakers respond to the output gap only in regime 1, when the expected inflation is close to the target and the exchange rate misalignment is low. When inflation and/or exchange rates are in their outer regimes monetary policy does not respond to the output gap as we find $k_{22} = k_{32} = k_{42} = 0$.

Second, policy does not respond to the exchange rate when the exchange rate misalignment is small as we find $k_{13} = k_{33} = 0$ in regimes 1 and 3. Policy only responds to the exchange rate when the economy is in the outer exchange rate regime, that is, when exchange rate misalignment is large. Further the response on exchange rate does not depend on the inflation regimes as we find $k_{23} = k_{43}$

Third, policy does not respond to inflation when the economy is in the inner inflation regime ($1.978 \leq \pi_{t+1} \leq 2.768$) as we find $k_{11} = k_{21} = 0$ in regime 1 and 2. Policy, however, responds to inflation vigorously when it is less than the lower threshold or greater than the upper thresholds.

Further, we find that policy response to inflation in regime 4 is greater than regime 3 ($k_{31} < k_{41}$). This implies that the response to inflation is more muted when there is significant exchange rate misalignment. For instance, the increase in interest rates in response to excessive inflation is moderated when the real exchange rate is significantly overvalued. This is plausible since the overvaluation also creates downward pressure on inflation.

To sum up, the estimates of augmented Taylor rule in each regime are consistent to the analytical framework presented in Table 5.1. There is an asset price effect in regime 2 and inflation effect in regime 3. Regime 4 comprises both inflation and asset price effects.

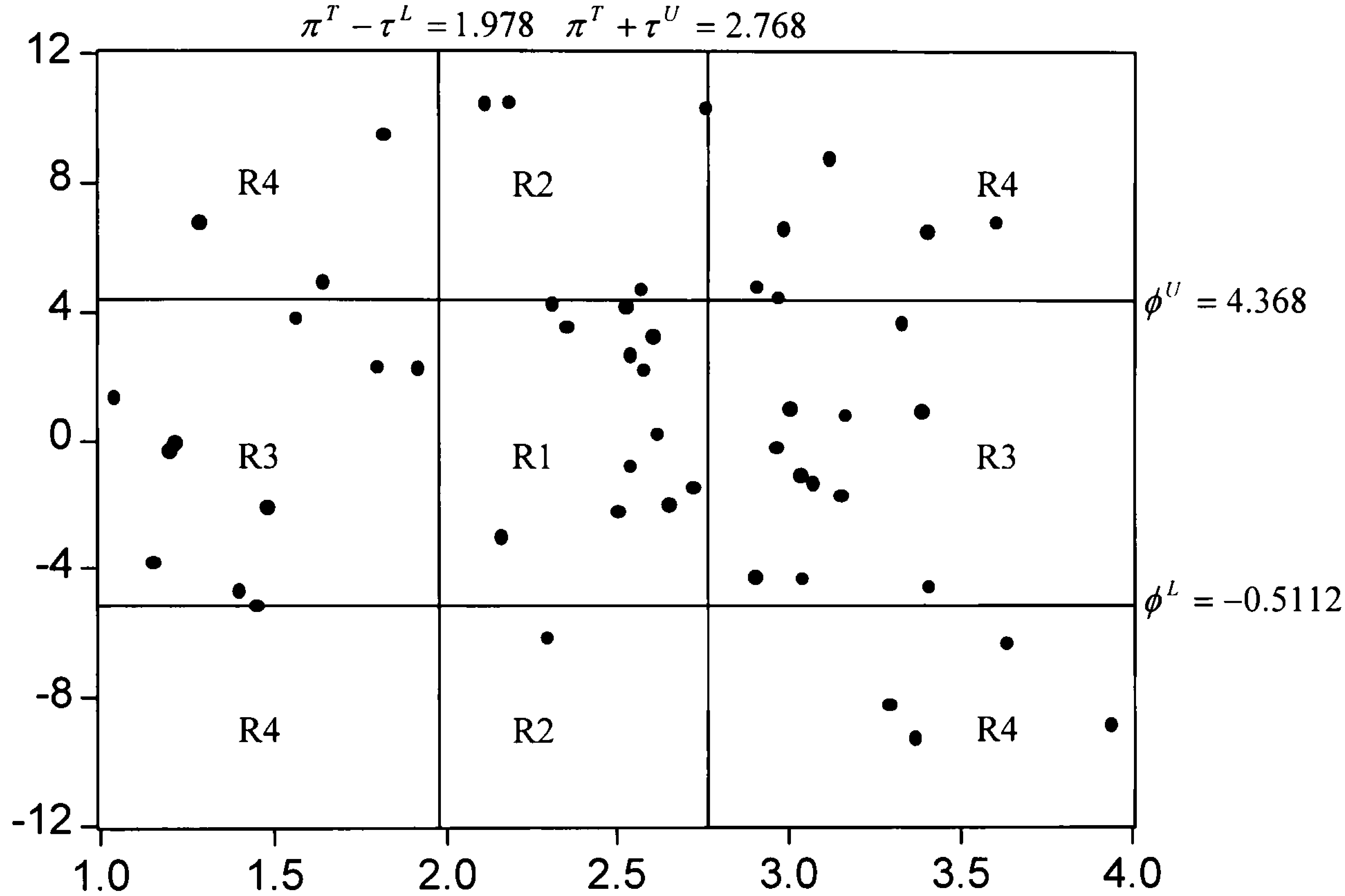
5.4.3.3 Classification of observations by regime

Figure 5.2 shows the distribution of observations over four distinct regimes. The horizontal axis measures inflation and the vertical axis measure the exchange rate misalignment. Out of total 51 observations in the sample, we have 11 observations in regime 1. These are the periods when policy responded only to the output gap as the economy was characterized by a low inflation and small exchange rate misalignment.

There are 6 observations in regime 2 when policymakers responded only to the exchange rate and 21 observations in regime 3 when policy responded only to the inflation. There are 13 observations in regime 4 when policy responded to both the exchange rate and inflation together.

Figure 5.3 further classifies the observation into different regimes over the years. The detailed classification is presented in Annex 5.1. We find that the economy was in regime 4 during late 1992 to mid 1993 due to high inflation and a large under valuation of sterling against foreign currencies. However, the problem was quickly corrected as the economy returned in regime 1 in early 1994.

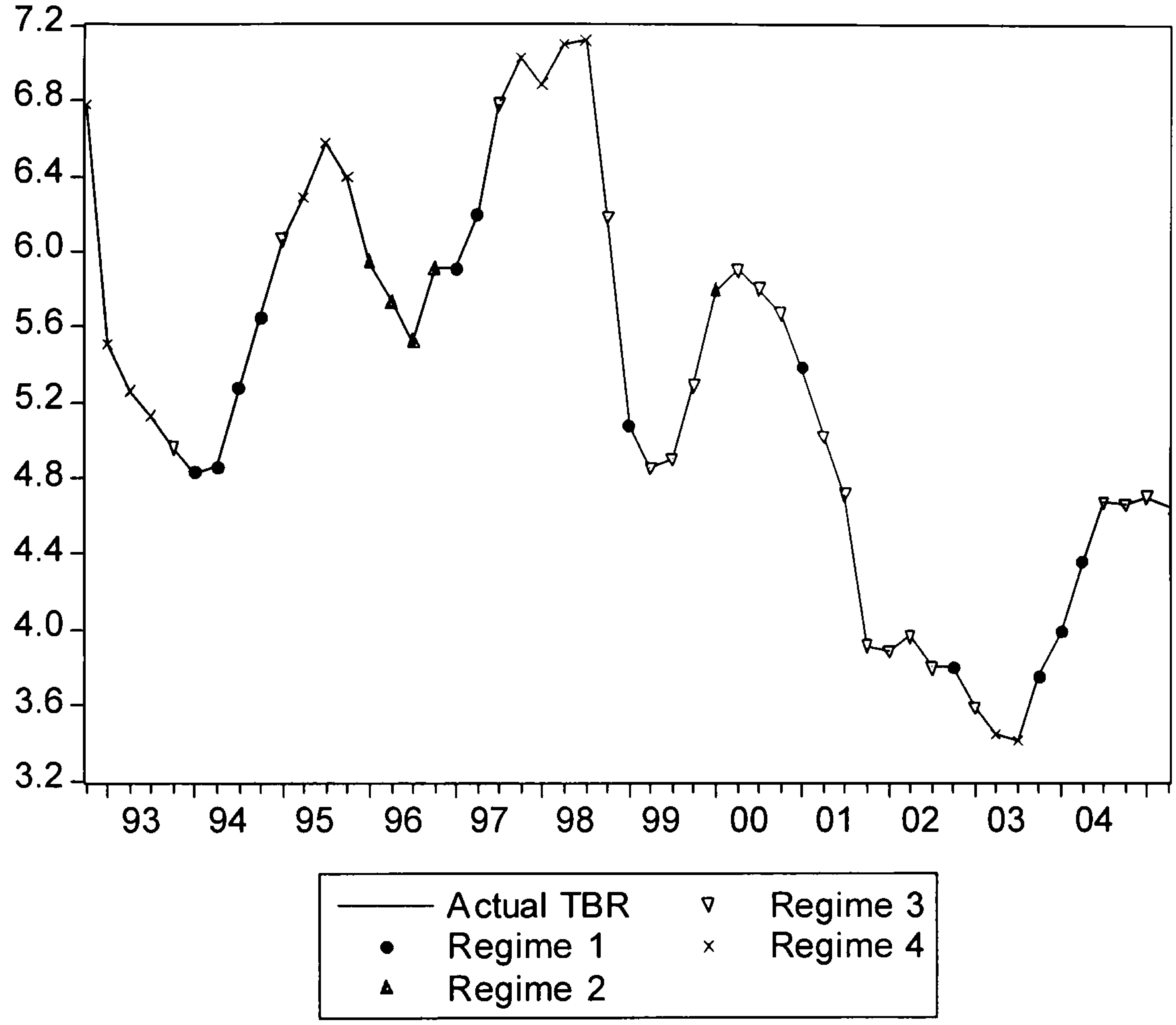
Figure 5.2: Distribution of asset prices (transition variables) over regimes



Note: (a) $\tau^L = -0.522$, $\tau^U = 0.268$ $\phi^L = -5.112$ and $\phi^U = 4.368$

(b) R1 = Regime 1, R2 = Regime 2, R3 = Regime 3, R4 = Regime 4

Figure 5.3: Classification of interest rate in different regimes



Note: Definition regimes

Regime 1: $(-5.112 \leq (e_t - e_t^*) \leq 4.368)$ and $(1.978 \leq \pi_{t+1} \leq 2.764)$;

Regime 2: $((e_t - e_t^*) < -5.112$ or $(e_t - e_t^*) > 4.368)$ and $(1.978 \leq \pi_{t+1} \leq 2.764)$.

Regime 3: $(-5.112 \leq (e_t - e_t^*) \leq 4.368)$ and $(\pi_{t+1} < 1.978$ or $\pi_{t+1} > 2.764)$.

Regime 4: $((e_t - e_t^*) < -5.112$ or $(e_t - e_t^*) > 4.368)$ and $(\pi_{t+1} < 1.978$ or $\pi_{t+1} > 2.764)$.

During mid 1995 the economy again went back to the regime 4 as inflation was high and the Sterling Pound was under valued during this period. Notice that the undervaluation of currency during this period was the highest in UK since 1992. The BoE adopted an aggressive monetary policy during this period to correct these anomalies. As a result, the currency was over-valued between 1997 and 1998 and the inflation was controlled.

Interestingly, the economy never moved in regime 4 except for two short episodes (1997Q4-1998Q3 and 2003Q2-Q3) since the Bank of England enjoys with operational independence in 1997. Our conclusion, therefore, supports to the recent finding that the degree of central bank's autonomy has a positive impact on the performance of the explicit inflation targeting (Bernake et al 1999).

5.4.4 Sensitivity analysis

To check robustness of our nonlinear estimates, we experiment some alternative specifications. To start with, we use a three-year moving average to proxy the equilibrium REER as an alternative to the Hodrick-Prescott trend. The REER gap is then obtained by deducting moving average trend from the actual series. The empirical estimate employing this new definition of REER gap is presented in column (ii) of Table 5.3.

Column (iii) of Table 5.3 uses the Euro area money market rate as an alternative to the US rate. In column (iv) we use the retail price index, which excludes mortgage interest rate (RPIX) as an alternative to RPI. Interestingly, none of them altered our major findings.

5.5 Concluding remarks

This chapter has examined the complex response of monetary policy in UK using a multiple regime smooth transition autoregressive model over 1992Q4 to 2005Q2. The major contributions of this chapter are as follows:

First, monetary policy in UK is sensitive to the exchange rate and inflation regimes. We find that the Bank of England responds to inflation and the exchange rate only when they are in their outer regimes. More precisely, the Bank responds to the exchange rate if domestic currency under valuation is greater than 4% or over valuation exceeds 5%. Similarly, policy responds to inflation only when expected inflation is less than 1.98% or greater than 2.76%.

Second, the policy response to the exchange rate misalignment does not depend on inflation regimes but the response to inflation does depend on the exchange rate regime. Third, policymakers only respond to output gap when they do not have to respond to asset prices or inflation, that is, when inflation and/or the exchange rate are in their inner regimes.

Fourth, the exchange rate misalignment alone can not capture the effect of open economy to full extent as the Bank of England responds to the foreign interest rate together with the REER misalignment. The response to the foreign interest rate, however, is not affected by the inflation and exchange rate regimes or by any other variables.

Although this chapter provides some new and noble insights of UK monetary policy, there is scope of further research. First, our nonlinear model in this chapter assumed that policy response in the lower and the upper regime is same as the outer regime combines both of them. This may not happen in practice as policy response may be different for the lower and upper regimes. For instance, policy response on higher inflation accompanied by a sharp exchange rate undervaluation might be different than the policy response on a higher inflation accompanied by a sharp overvaluation of Pounds. Therefore it would be interesting to estimate a model which provides three regimes for inflation and three regimes for exchange rate misalignment, making a total of 9 regimes. In this case we would be able to analyze the policy response on a large overvaluation/undervaluation of sterling pound with expected inflation less/greater than the regime boundaries separately.

Secondly, it would also be interesting to include other asset prices specially, house prices and share prices in the nonlinear reaction function. Third we can consider a separate regime for output gap to get further insights of UK monetary policy. We intend to carry on this work in future.

Chapter 6

Summary and Conclusion

Many central banks have adopted inflation targeting since early 1990s because of the failure in stabilizing economy through the exchange rate anchor and monetary aggregates. Now, there is a consensus among policymakers, economists and general public that low and predictable inflation helps to promote economic efficiency and growth in the long run. But it is also argued that the macroeconomic stability in general and price level stability in particular are important preconditions for economic growth (Fisher, 1993).

Inflation targeting regime has been able to control inflation. However, the asset prices in the financial markets have been more volatile during this period. On the other hand the international financial market has been integrating rapidly. As a consequence, the literature debates whether monetary policy responds to asset prices and international market in practice to keep inflation under control in the long run. Similarly, the literature also debate whether policy responds to inflation precisely in practice.

In this context, the objective of this research has a three-fold. The first objective is to investigate if and/or to what extend does monetary policy respond to asset prices. The second objective is to assess whether or not monetary policy targets inflation precisely in a way it is announced. And finally, to analyze whether monetary policy responds to foreign interest rates and the real exchange rate misalignments; and whether the policy reaction to them depends on the state of inflation and vice-a-versa.

The empirical analysis is carried out using quarterly data of UK throughout this research while the US data is also used in Chapter 2. There are similarities between these two countries in the conduct of monetary policy. The BoE has been targeting inflation since October 1992 after the European Exchange Rate Mechanism (ERM) during October 1990 to September 1992 and monetary targeting earlier in the 1980s (Haldane, 1995). The Federal Reserve, however, does not target inflation explicitly but implicitly being closed to the way of explicit targeting, especially when Volkar was appointed as the chairman of the Fed in 1979 (Clarida et. al., 2000).

We start our analysis by analyzing whether monetary policy responds to asset prices collectively. To do this, we first develop the FCI, which is a weighted average of the real interest rate, the real exchange rate, real share prices and the real house prices, and then estimate the FCI augmented Taylor rule. A significant FCI coefficient implies that monetary policy responds to asset prices collectively.

However, instead of using the IS curve as in the conventional literature, we explore an alternative methodology using an open economy macroeconomic structural model for obtaining the FCI weights. We provide two alternative weighting procedures, one for a strict CPI inflation targeting framework and another for a flexible inflation targeting framework.

Using quarterly data over 1979 to 2003, we construct FCIs for the US and the UK and find them to be useful for describing the monetary policy stance. We, then, estimate the FCI augmented Taylor rule as an alternative to a simple Taylor rule. We find that the FCI-augmented Taylor rule is significantly better than the simple rule for both countries. As a result, we conclude that monetary policy responds to asset prices by responding to the FCI.

Chapter 3 has two objectives - to verify the findings of chapter 2 using an alternative specification and to test whether or not monetary policy is nonlinear. In order to furnish the first objective, we estimate asset price augmented Taylor rule. We argue that if the policy responds to asset prices collectively (chapter 2) then each asset prices that were included in the FCI must be significant when included in the Taylor rule. As expected, the estimate of asset price augmented reaction function is found to be better than a simple reaction function with obtaining significant coefficients of asset prices. Chapter 2 and 3, therefore, suggest that monetary policy responds to asset prices together with inflation and the output gap in practice.

As discussed, the second objective of chapter 3 is to investigate whether monetary policy is nonlinear and whether or not it responds to exchange rate misalignments. To do so, this chapter employs varieties of nonlinear models such as Granger and Lee (1989), Escribano and Granger (1998), Escribano and Aparicio (1999) and van Dijk et al. (2002). Estimates of these models suggest that monetary policy is nonlinear, the policy response to inflation is asymmetric. Monetary policy in UK aims to keep inflation within a rage rather than pursuing a point target. Further, we find that the policy response to exchange rate misalignments is strongest when inflation is close to the target compared to a weaker response when it is far from the target.

The nonlinear analysis in Chapter 3, however, is based on the RER misalignment augmented-Taylor rule with two-regime STAR model. This model does not address the second and the third objectives of this research. Chapter 4, therefore, estimates the foreign interest rate augmented Taylor rule using a three-regime STAR he model. Further, the main objective of this chapter is to investigate whether policy response to high inflation and a low inflation is same.

Chapter 3 and 4 both find that the UK monetary policy is nonlinear and policy response to inflation is asymmetric although they use different models. While the former chapter estimates an exchange rate augmented Taylor rule, the latter chapter uses a foreign interest rate augmented Taylor rule. Chapter 5, therefore, combines these two variables together using a four regime STAR model to assess whether foreign interest rates and exchange rate misalignments are to substitute each other.

This chapter also aims to investigate whether monetary authority considers a separate asset price regime together with inflation regime and whether asset price regime has any impact in response to inflation and vice-a-versa.

Our main empirical findings can be summarised as follows. First, we find that monetary policy is forward looking, as one quarter ahead forward looking Taylor rule outperforms any other specification.

Second, the policy reaction to inflation is strongest followed by the response to the output gap, the foreign interest rate, the exchange rate, house prices and share prices.

Third, monetary policy does not respond to inflation when expected inflation is less than the lower threshold but it's response to inflation is vigorous when expected inflation exceeds the upper threshold. Moreover, we find that the upper inflation threshold is just slightly higher than the target of 2.5% but the lower threshold is far below the target though the BoE has to give a formal clarification to the government if inflation deviates for more than 1% in either direction from the target. These all suggest that monetary policy is deflationary bias and policy aim to keep inflation within a range rather than pursing a point target.

Fourth, monetary policy in UK considers a separate exchange rate regime together with inflation regime. The BoE responds to inflation and exchange rates only when they are in their outer regime. More precisely, the Bank responds to the exchange rate only if domestic currency under-valuation is greater than 4% or over-valuation exceeds 5%. Similarly, policy responds to inflation only when expected inflation is less than 2% or greater than 2.75%.

Fifth, the monetary policy response to exchange rate misalignments does not depend on inflation regime but the response to inflation does depend on the exchange rate regime.

Sixth, policymakers respond to the output gap only when they do not respond to asset prices or inflation, that is, when inflation and the exchange rates are in their inner regimes.

Finally, we find that neither the exchange rate misalignment nor the foreign interest rate alone can capture the open economy effects; monetary policy responds to both variables. Unlike the policy response to exchange rate misalignments, we find that policy reaction to the foreign interest rate is unaffected by the inflation or the exchange rate regimes.

Further research scope

There are several interesting issues on the topic, which we could not address in this research. It is because our sample size is relatively small to model those issues as the inflation targeting regime in UK starts from 1992.

First, we defined two regimes for the exchange rate and two regimes for inflation, making a total of four regimes in Chapter 5. This framework assumes that policy response to a large undervaluation and a large overvaluation as same. This assumption may not be true in practice as policy response may vary between a large undervaluation and a large overvaluation of the domestic currency vis-à-vis foreign currencies. Therefore, it would to interesting to have a model with three regimes for the exchange rate and three regimes for inflation, making a total of nine regimes.

Second, although we found that policy response to the output gap is stronger after inflation, we did not consider regimes for this variable. It would be interesting to analyze whether monetary policy is affected by business cycle by defining regimes for the output gap appropriately.

Third, although linear estimates in chapter 2 and 3 provide ample evidence that monetary policy responds to equity prices and property prices, they are not included in nonlinear models. Therefore, it would be interesting to assess the behaviour of monetary policy by including all asset prices in the nonlinear framework. We intend to carry on all these issues in future when there are sufficient time series data within the inflation targeting regime.

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Appendix 2.1: Definition and sources of variables

Variable	UK	USA
CPI	CPI excluding mortgage interest	CPI all times
Output	Real GDP	Real GDP
Nominal interest rate (R)	3 month treasury bill rate	Effective federal fund rate
Exchange rate (e)	REER	REER
House price index (hp)	Nationwide House Price Index*	Average sale price of one family houses**
Share price index (sp)	FUTSE All (share price index)*	Dow Jones Index (Industrial Share Price)*
OP	Oil price	Oil price

Source: Unless otherwise stated, variables are abstracted from International Financial Statistics CD-ROM, January 2004.

* Source: Datastream

**source: National Association of Rotators.

Appendix 2.2: Unit Root Tests

2.2.1 Augmented Dickey-Fuller (ADF) test

We employ the following augmented Dickey-Fuller (ADF) test to investigate the stationary process of variables, x_t, listed in Table 2.3.

$$\Delta x_t = \gamma_0 + \gamma x_{t-1} + \sum_{i=1}^{k} \gamma_i \Delta x_{t-i} + \varepsilon_t \tag{A2.1}$$

Where, γ and γ_t are parameters to be estimated and ε_t is a random disturbance term defined as: $\varepsilon_t \sim iid(0, \sigma_\varepsilon^2)$. The null and alternative hypotheses are defined as:

$$H_0 : \gamma = 0$$

$$H_1 : \gamma < 0 .$$

We evaluate the null hypotheses using the following t-ratio, t_γ, for γ and compare it to the critical values, $t^{Critical}$, available at MacKinnon (1991).

$$t_\gamma = \frac{\hat{\gamma}}{se(\hat{\gamma})} \tag{A2.2}$$

where $\hat{\gamma}$ is the estimate of γ and $se(\hat{\gamma})$ is the standard error. In this case, if $t_\gamma < t^{Critical}$ we reject the null hypothesis, implies that the variable, x_t, is stationary. Accepting the null implies x_t contains a unit root (see among others Harris, 1995).

2.2.2 Phillips Perron (pp) test

Phillips and Perron (1988) provide a nonparametric method of controlling for serial correlation when testing for a unit root, an alternative to the ADF test. This method estimates the non-augmented Dickey-Fuller test equation, i.e. by excluding $\sum_{i=1}^{k} \gamma_i \Delta x_{t-i}$ from Eq. (A2.1), and modifies the t-ratio of the coefficient, γ, as follows so that serial correlation does not affect the asymptotic distribution of the test statistic.

$$t^{PP} = (\alpha / \beta)^{1/2}[\hat{\gamma} / se(\hat{\gamma})] - T(\beta - \alpha)se(\hat{\gamma}) / 2\beta^{1/2}S \qquad \text{(A2.3)}$$

Where S is the standard error of the test regression, $\alpha = (T-k)S^2 / T$, β is an estimator of the residual spectrum at frequency zero, and t^{PP} is the modified t-statistics. The remaining parameters, hypothesis and the decision rule are same as in the ADF test.

2.2.3 Non-linear unit root test

It is argued that the linear unit root tests such as ADF and PP tests are less powerful if the data adjustment process is non-linear (Gregoriou and Kontonikas, 2006). Therefore, a potential failure of rejecting non-stationarity in many time series data may be the result of the linear unit root tests. In this context, following Kapetanious, Shin and Snell (2003) we verify the ADF and PP test results employing a non-linear unit root test as shown below.

$$x_t = \phi x_{t-1} + \varphi x_{t-1}[1 - e^{-\theta x_{t-1}^2}] + u_t \quad u_t \sim iid(0,\sigma_\varepsilon^2) \qquad \text{(A2.4)}$$

Eq. (A2.4) is an exponential smooth transition autoregressive (ESTAR) model which provides a symmetric adjustment for x_t towards its mean. In this model, if ϕ=1 and θ =0 then x_t follows a random process. Similarly, x_t is stationary if θ >0.

Since θ is a nuisance parameter, an evaluation of unit root by estimating (A2.4) is not a feasible option. Therefore, we employ the following first-order Taylor series approximation to (A2.4) under the null with allowing for serial correlation in u_t (see Gregoriou and Kontonikas, 2006).

$$\Delta x_t = \gamma_0 + \gamma x_{t-1}^3 + \sum_{i=1}^{k} \gamma_i \Delta x_{t-i} + \varepsilon_t \qquad \text{(A2.5)}$$

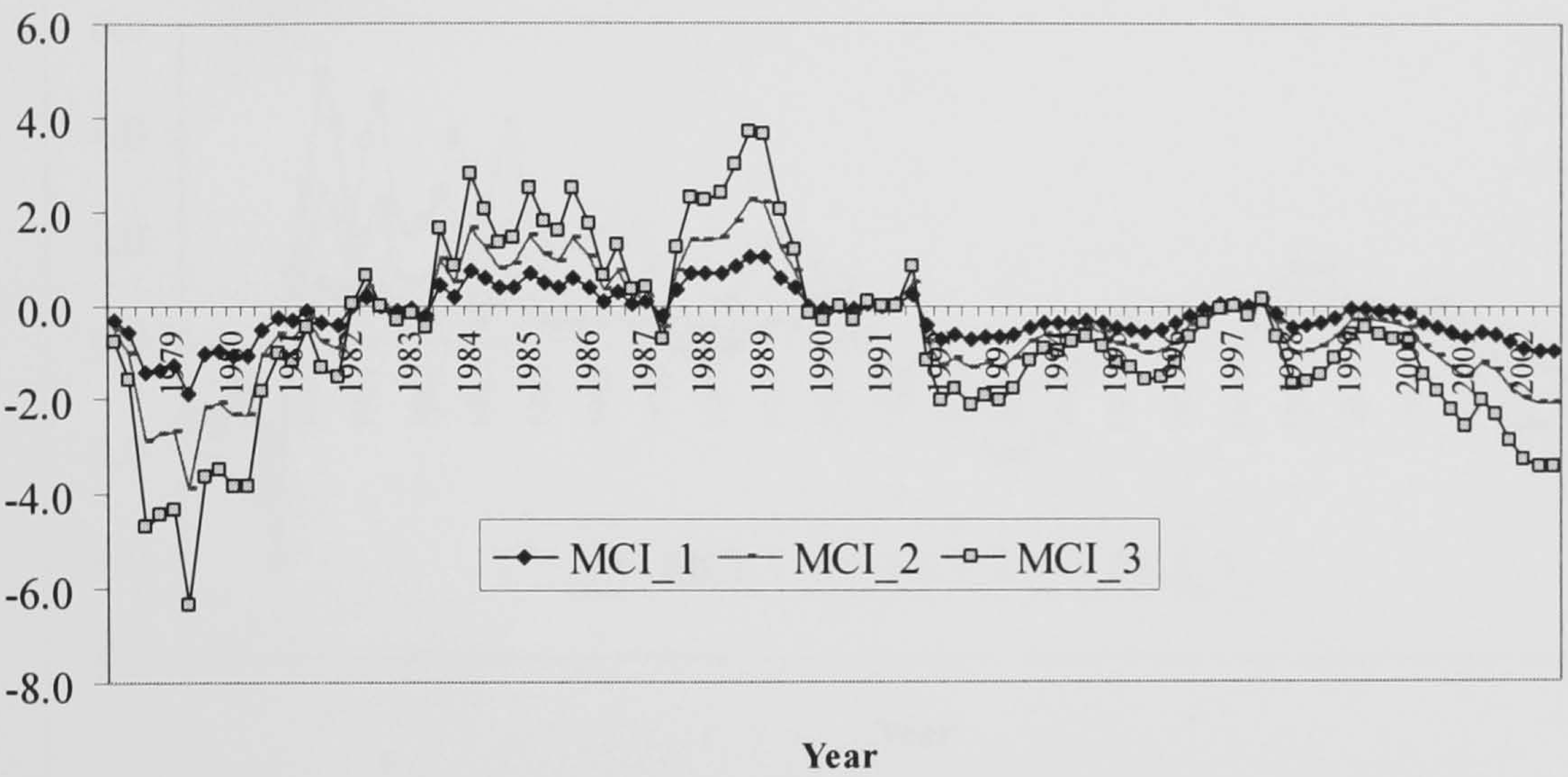
Eq. (A2.5) is a representation of Eq. (A2.4) where the null hypothesis is defined as γ=0. However, MacKinnon (1991) critical value is not applicable to test the significance of γ because the cubic term embedded in γ is a non-linear function. In this context, we could use a bootstrap technique to obtain an asymptotic t-statistics as in Gregoriou and Kontonikas (2006) but, for the simplicity, we use Kapetanious, Shin and Snell (2003) to evaluate γ.

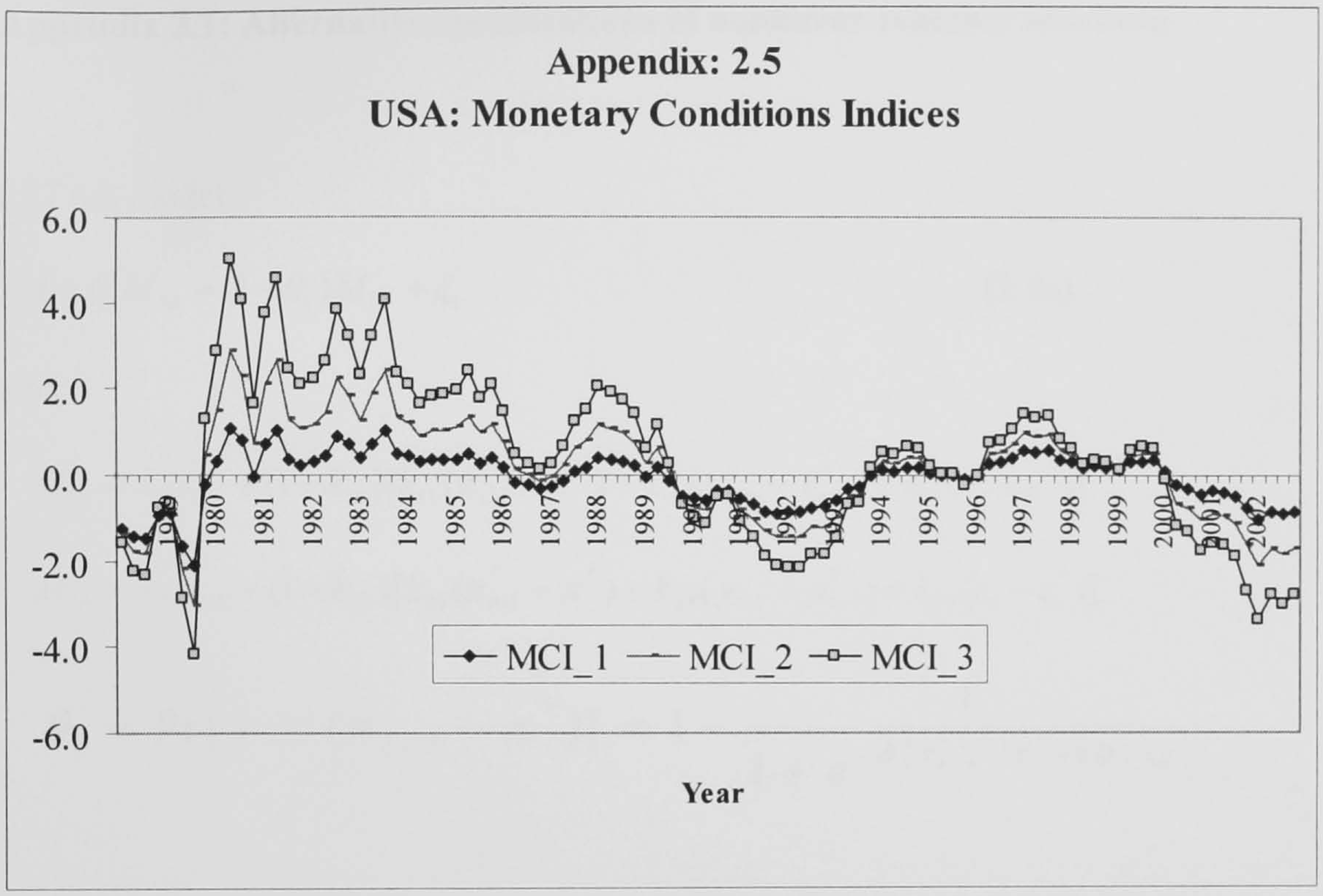
Appendix 2.3: MCI weights

Variables	CPI Inflation Targeting Framework (MCI_1)	Domestic Inflation Targeting Framework (MCI_2)	Benchmark Specification (MCI_3)
Panel A: UK			
Real Interest Rate	0.267	0.550	0.895
REER	0.733	0.450	0.105
Panel B: USA			
Real Interest Rate	0.291	0.548	0.858
REER	0.709	0.452	0.142

Note: Calculations are based on the formula given by Table 2.2 and estimated parameters given by Table 2.4 and 2.5.

Appendix: 2.4
UK: Monetary Conditions Indices




Appendix: 2.5
USA: Monetary Conditions Indices
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1994
1995
1996
1997
1998
1999
2000
MCI_1
MCI_2
MCI_3
Year

Appendix 3.1: Alternative specifications of nonlinear reaction functions

A. LSTAR model

$$i_t = \bar{i} + \theta_t M_{Lt} + (1-\theta_t) M_{Ut} + \xi_t \tag{3.9a}$$

where,

$$M_{Lt} = k_{10} i_{t-1} + (1-k_{10})[k_{11}(\pi_{t+1} - \pi^*) + k_{12}(y_{t+1} - y^*_{t+1}) + k_{13}(e_t - e^*_t)]$$

$$M_{Ut} = k_{20} i_{t-1} + (1-k_{20})[k_{21}(\pi_{t+1} - \pi^*) + k_{22}(y_{t+1} - y^*_{t+1}) + k_{23}(e_t - e^*_t)]$$

$$\theta_t = \Pr\{\tau \geq (\pi_{t-d} - \pi^*)\} = 1 - \frac{1}{1 + e^{-\sigma(\pi_{t-d} - \pi^* - \tau])/s_\pi}}$$

B QL-STAR model

$$i_t = \bar{i} + \theta_t M_{It} + (1-\theta_t) M_{Ot} + \xi_t \tag{3.10a}$$

Where,

$$M_{It} = k_{10} i_{t-1} + (1-k_{10})[k_{11}(\pi_{t+1} - \pi^*) + k_{12}(y_{t+1} - y^*_{t+1}) + k_{13}(e_t - e^*_t)]$$

$$M_{Ot} = k_{20} i_{t-1} + (1-k_{20})[k_{21}(\pi_{t+1} - \pi^*) + k_{22}(y_{t+1} - y^*_{t+1}) + k_{23}(e_t - e^*_t)]$$

$$\theta_t = \Pr\{\tau^L \leq (\pi_{t-d} - \pi^*) \leq \tau^U\} = 1 - \frac{1}{1 + e^{-\sigma(\pi_{t-d} - \pi^* - \tau^L)(\pi_{t-d} - \pi^* - \tau^U)/s_\pi}}$$

Appendix 3.2: Alternative estimate of nonlinear reaction functions

(1992Q4-2004Q2)

	LSTAR (Estiamte of eq. 3.9a)	QLSTAR (estimate of Eq. 3.10a)
$\bar{i}$	0.471 (0.208)*	0.335 (0.179)**
	M_L	M_I
k_{10}	0.873 (0.041)*	0.919 (0.034)*
k_{11}	0.870 (0.459)***	1.534 (0.898)***
k_{12}	2.953 (1.301)**	3.120 (1.593)**
k_{13}	0.169 (0.084)***	0.101 (0.031)**
	M_U	M_O
k_{20}	0.876 (0.038)*	0.905 (0.032)*
k_{21}	3.914 (1.273)*	5.504 (2.034)*
k_{22}	1.299 (0.978)	2.498 (1.280)**
k_{23}	0.026 (0.010)*	0.046 (0.015)**
τ	-0.370 (0.017)*	
τ^L		-1.089 (0.078)*
τ^U		0.728 (0.086)*
σ	223.9 (154.1)	81.8 (127.9)
Diagnostic tests		
$\overline{R}^2$	0.93	0.92
Standard Error	0.24	0.25
AIC	0.14	0.09
D-W Statistics	1.94	1.97
LM4	1.26 [0.30]	1.49 [0.23]
ARCH4	1.88 [1.15]	0.71 [0.58]

Heteroskedasticit	0.55 [0.83]	0.78 [0.64]
Normality	2.10 [0.34]	1.02 [0.60]
Hypothesis testing		
a. Test against Linear model: $k_{1i} = k_{2i}$	3.69 [0.01]	8.50 [0.00]
b. Inflation Persistence: $k_{11} = k_{21}$	5.74 [0.02]	4.37 [0.04]
c. Policy symmetric: $\pi^* = (\pi^* - \tau^L + \pi^* + \tau^U)/2$		6.25 [0.01]
d. No effective lower band: τ^L =0		3.20 [0.08]
e. No effective upper band: τ^U =0		13.8 [0.00]
f. Interest rate persistence: $k_{10} = k_{20}$	0.01 [0.91]	0.96 [0.33]

Notes: Please see Table 3.2 for the footnotes and Appendix 3.1 for the model reference.

Appendix 5.1: Classification of monetary policy by Regimes (1992Q4 –2005Q2)

Period	TBR	Regime
Q4 92	6.780	Regime 4
Q1 93	5.510	Regime 4
Q2 93	5.260	Regime 4
Q3 93	5.130	Regime 4
Q4 93	4.960	Regime 3
Q1 94	4.830	Regime 1
Q2 94	4.860	Regime 1
Q3 94	5.280	Regime 1
Q4 94	5.650	Regime 1
Q1 95	6.060	Regime 3
Q2 95	6.290	Regime 4
Q3 95	6.570	Regime 4
Q4 95	6.390	Regime 4
Q1 96	5.940	Regime 2
Q2 96	5.730	Regime 2
Q3 96	5.520	Regime 2
Q4 96	5.910	Regime 2
Q1 97	5.910	Regime 1
Q2 97	6.200	Regime 1
Q3 97	6.780	Regime 3
Q4 97	7.030	Regime 4
Q1 98	6.890	Regime 4
Q2 98	7.100	Regime 4
Q3 98	7.120	Regime 4
Q4 98	6.190	Regime 3
Q1 99	5.080	Regime 1

Period	TBR	Regime
Q2 99	4.860	Regime 3
Q3 99	4.910	Regime 3
Q4 99	5.300	Regime 3
Q1 00	5.800	Regime 2
Q2 00	5.910	Regime 3
Q3 00	5.810	Regime 3
Q4 00	5.680	Regime 3
Q1 01	5.390	Regime 1
Q2 01	5.030	Regime 3
Q3 01	4.720	Regime 3
Q4 01	3.920	Regime 3
Q1 02	3.890	Regime 3
Q2 02	3.970	Regime 3
Q3 02	3.800	Regime 3
Q4 02	3.800	Regime 1
Q1 03	3.590	Regime 3
Q2 03	3.450	Regime 4
Q3 03	3.410	Regime 4
Q4 03	3.760	Regime 1
Q1 04	3.990	Regime 1
Q2 04	4.370	Regime 1
Q3 04	4.680	Regime 3
Q4 04	4.670	Regime 3
Q1 05	4.710	Regime 3
Q2 05	4.660	Regime 3